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MANAGEMENT AND METHODS IN CONCRETE HIGHWAY CONSTRUCTION

MANAGEMENT AND METHODS IN CONCRETE HIGHWAY CONSTRUCTION

BY

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PREFACE

The construction of a concrete pavement is a manufacturing process in which labor and machinery are used to handle, treat, and place in final position those materials which are the necessary ingredients of the pavement. The contractor's problem is to obtain a profit from this work. He desires to do good work. Commonly he is willing to follow any reasonable course of action in order to secure good work. Nevertheless, his primary objective is profit. This he must have or he must go out of business. But the question of whether an operation will yield a good profit or net a serious loss is largely dependent on the skill with which the labor he employs and the equipment he owns are used. For this reason, the management of production and the use of appropriate production methods are of paramount importance to contractors and to their superintendents.

A discussion of these matters should also be of value to designing engineers in that a more complete knowledge of the elements which affect cost should enable them to give a broader consideration to these matters when design and specifications are under consideration. Construction engineers and inspectors also will find a knowledge of the principles of production management and of good construction practice of assistance, for, though their primary objective is quality, a knowledge of the principles and the practices of efficient management should make it a simpler matter to secure the desired quality without endangering the contractor's profit.

This discussion of the management of production and of appropriate methods has, then, been prepared primarily for contractors and their superintendents, and for engineers who are dealing with the various phases of concrete pavement construction. On this account, it has been possible to eliminate many of the details which would be desirable in a book especially prepared for the instruction of men unfamiliar with the technique of this work. On the other hand, an effort has been made to include enough of the details, particularly of important methods and practices, so that any of these can be readily followed by men who, though unfamiliar with the particular practice discussed, have a reasonable familiarity with concrete paving work in

general, and so that students not particularly familiar with the paving field may, nevertheless, gain a clear view of what factors affect the efficiency of production and of how they influence the selection of methods and practices, as well as the cost of the finished work.

The construction of work of any magnitude involves a considerable number of activities more or less independent of, though related to, the management of production. Among these, securing the work, financing it, employing the personnel, buying materials, insuring their delivery as needed, accounting for funds expended, and analyzing the results which are being obtained through cost accounting are illustrative. They are not, however, so intimately related to the management of production that they require discussion in a book which is devoted to this subject and to a discussion of good construction practices. All discussion of such matters is, therefore, avoided as more appropriate in a discussion of the general field of management than in a discussion of that narrower field, the management of production.

The management of production is increasingly a science. Effect unalterably and unavoidably follows cause. As a science, management endeavors not only to determine cause accurately and specifically, but to determine it quantitatively, for it is only by so doing that effect can be accurately controlled. The output is low. This is an effect—the effect of a dozen causes, it may be. The causes may be accurately determined as poor operation of the mixer, inadequate truck supply, slow loading of trucks, etc., but even then the control can only be haphazard. It is only when the superintendent knows exactly what percentage of the working day is lost from each of these and from any other causes affecting production that he is in a position definitely to deal with the production problem. On the other hand, it is unavoidably true that some methods are basically more efficient than others. Therefore the attainment of proper production at the lowest cost requires both the application of scientific management and the use of what are basically the most efficient production practices. It is for this reason that the discussion of the two is combined.

For the data on which the discussions that follow rest, credit is due the U. S. Bureau of Public Roads, which has spent and is spending considerable sums in the scientific determination of the elements of cost in highway construction work and, through these

determinations, the basis of efficiency in this field. The data thus collected and the conclusions drawn are published from time to time in the Bureau's official organ—Public Roads. It has, however, appeared that a somewhat broader discussion of these matters would be helpful—a discussion in which the data developed by the Bureau's investigations would be somewhat amplified and more fully correlated with ordinary construction data. This text is based on these investigations, which have been made under the immediate direction of the author, and, in general, is confined to the amplification of the principles they have developed and to a discussion of where, how, and why these principles affect the cost of construction work. Insofar as this result is attained, this presentation has the official approval of the Bureau. On the other hand, the author has, at times, exercised the privilege of expressing his own views and wherever this has been done, cheerfully accepts full responsibility for them.

Credit is also due the Bureau for the illustrations used. All of these, including graphs, charts, etc., are from the Bureau's files, being but a small part of the large number collected in the course of the Bureau's investigations in this field.

Finally it may not be inappropriate to remark that a book must have a beginning and must follow some reasonable course to its conclusion. On a construction job, the management of production begins when plans for the prosecution of the work are made and because the work of management begins at that point, this discussion has been started at that point. Thereafter, the course of the discussion follows as closely as possible the order in which the work is accomplished. But in the nature of the case, exact harmony in this particular is impossible for there are points at which there is what may be described as an overlapping of operations, and there are points at which one service—the water supply, for instance—affects more than one operation. So, at times, the order of treatment may seem inappropriate and to those who feel that it is, it is only possible to reply that some other order of treatment doubtless would have done as well—better perhaps—which after all is of little consequence, for the purpose is to present the principles which govern management, to describe efficient construction practices and to show how these may be combined to the advantage of construction cost.

J. L. Harrison.

Washington, D. C.,
April, 1927.

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MANAGEMENT AND METHODS IN CONCRETE HIGHWAY CONSTRUCTION

CHAPTER I

PLANNING THE CONDUCT OF THE WORK

Most highway work is let on the basis of competitive bidding. The prevailing practice is to advertise that certain work is to be done and that tenders as to price will be received at a certain time and place. It is the generally accepted engineering theory that anyone who enters a tender prepares an estimate of cost on which his tender is based, the tender itself representing the best possible predetermination of cost, plus a profit. Estimates of this kind presuppose some plan of operation, for it is quite impossible to prepare an estimate of the cost of any sort of engineering structure which is of any value without such a plan, though in the nature of the case the plan may be wholly tentative and very general. But while it is the general assumption of engineers that tenders are based on estimates, in the highway field at least, this is far from the fact. The truth of the matter appears to be that many bidders make no preliminary study of the cost of the work on which they enter bids and that the cost analyses of a still greater number are of far too cursory a nature properly to be dignified as estimates. Nor, upon analysis, does this practice appear surprising or particularly improper. Concrete is rapidly coming to be a product which is almost as standard as pig iron or bar copper or corn. Every producer of such commodities is familiar with the fact that there is an established market price for them and that if he sells such products at all he must sell them at the market. For this reason, his problem as a producer is not properly to be described as one of selling at a profit but rather as one of producing at a profit. In other words, he cannot, in the nature of the case, calculate his cost, add a profit, and thus obtain

a selling price. He must take whatever selling price the market sets and obtain his profit by devising methods and practices which will keep his cost of production within this price.

The Bases on Which Bidding Is Done.—The paving contractor faces much this same situation. If the prevailing price of concrete pavement is $3 per square yard, a contractor cannot get more, no matter what he thinks it will cost him to produce it, and he is foolish to take less even though this price offers an unnecessarily wide margin of profit. He is not, therefore, particularly interested in the details of cost or in plans of operation at the moment a bid is entered; so his usual procedure is to give first consideration to the possibility that there may be unusual conditions attached to the project of the moment. If there are, their effect must be appraised, but beyond this he realizes that the market price must control his bid or he has no chance of obtaining the work. In a free rising market, he may be able to add a little to the price commonly bid and still obtain the work, while in a free falling market it may be necessary to shave the price in order to secure any work at all. But, whether the market of the moment is strong, stable or weak, a knowledge of what the market really is and of its trend is of more importance in successful bidding than is an estimate of cost, be that ever so accurate. The contractor's objective is to obtain the work and with it all the profit possible, and his chance of doing this is certain to be more influenced by a thorough knowledge of what others are bidding on similar work than by a knowledge of what such work is likely to cost him. There is nothing peculiar or unusual about this. It is merely the outward expression of the working of everyday business practices. The contractor must have work or he must cease to be a contractor. His natural attitude is that he can do the work as cheaply as anyone else. But whether he can or not, he must offer to do it as cheaply or cease to do this sort of work at all. Hence a knowledge of the market, the price at which others are offering to do similar work, is vital.

These facts will be so apparent to many that even this casual reference to them may seem to be out of place here. Engineering literature, however, is so impregnated with the idea that, in construction work, sales are made on the basis of a precalculated cost plus a profit that a brief statement of prevailing practices appears to be rather a necessary preface to the comments

on planning which follow. It may also be appropriate to add that a more general appreciation of the fact that a large amount of work is taken every year by men who, at the moment the work is obtained, have no idea of how they will make a profit on it should tend to make those responsible for the enforcement of plans and specifications more careful that in their perfectly proper pursuit of quality there is no unnecessary interference with the contractor's chance of obtaining a profit.

The Purpose of Construction Plans.—The above discussion will explain why it is so commonly true that the preparation of the plan of operation is left until work is about to start. Working out a construction plan takes time and effort, and time, particularly the time of men competent to prepare valuable construction plans, costs a good deal. There is, therefore, both reason and judgment in limiting the preparation of such plans to work in hand. Moreover, with the job in hand and the price that will be received for it established, there is a definite basis from which to work. Cost must be kept below that price. Admittedly occasions will arise when this will prove impossible. In such cases the work will be handled at a loss. Nevertheless, the objective is profit, and the obvious purpose of the man who makes the plans which will govern the conduct of the work is to create a situation under which a profit is possible.

On the other hand, in the nature of the case, good planning does not insure a profit, for not even the best of planning can guarantee correct performance. Rather the purpose in planning is, through careful study of the job and of the conditions surrounding it, to guard against the adoption of any course of action which is basically unsound or which, on closer analysis, could have been shown to preclude profitable operation and to establish a sound basis on which to control the work when construction begins. These are more important considerations than commonly is supposed, for the modern construction operation—and particularly is this true of concrete paving work—comprises so many interrelated activities that even a minor error in the plans may adversely affect production during the whole job, and of course no rational control of the rate of production can be exercised without a definite predetermined plan.

Determining the Day's Work.—In developing plans for construction, certain decisions have to be made, the general construction plan depending rather definitely on these decisions.

The first of these involves the number of hours' work that will be done each day. In deciding this matter the customs which prevail in the locality where the work is to be done must be given much weight for almost unavoidably a good deal of local labor will be employed. But the real importance of this decision is not so likely to come from any effect which it has on wages or on the ease with which the necessary labor is secured as it is from the effect which it has, or can be made to have, on the business-like prosecution of the work. There is no end to concrete paving jobs which average no more than 6 or 7 hours of production a day, largely because the plan of operation is vague and because there is a lack of emphasis on the responsibility which rests on the job management to obtain 10 hours of work from every 10 working hours.

Causes of Short Working Day.—Short days are caused by any number of things, but the most important cause is the practice of going out to the job in the morning and at noon "on the boss's time." It is easy enough to waste half an hour twice a day in this fashion. Another important cause of lost time is the practice of letting the mixer operator go out with the rest of the men. It is difficult to get the work started in less than from 10 to 15 minutes after the operator arrives. Therefore, unless he is required to report before the rest of the force, and to have the mixer running at the moment work is supposed to start, time will be lost from this cause. Wet weather and generally unpleasant weather often become an excuse for shutting down the work before they are, in fact, a reason for so doing. Breakdowns cause lost time. Moves are poorly planned and minor difficulties cause delays because they have not been foreseen and the method of meeting them thought out. This is not a complete list of the factors which affect the length of the working day, but it is not at all necessary that a complete list be given, for the purpose is to draw attention to the fact that, as a general condition, the time losses which cause the short average working day generally prevailing on concrete paving jobs can be traced to specific job practices. In any thoughtful effort to produce at a profit, these must be subjected to analysis for the purpose of determining whether they are necessary and therefore ought to be retained as accepted practices or whether they ought to be changed.

Nominal Working Day May Differ from Actual Working Day. Speaking in general terms, a low average number of hours worked

per day indicates lax job management. On the other hand custom may dictate the use of practices which are not wholly satisfactory to a good production manager. But once the customs and practices commonly accepted are reviewed and a decision is rendered as to which of these will be recognized on the specific job under scrutiny, it is a relatively simple matter to establish the average length of the working day which can be made to control operations on the job in hand. This, it may be remarked, may be quite different from the nominal working day. But whether the two are similar or are quite different, they should never be confused. Production can be scheduled only on the basis of the number of hours during which the mixer will operate. It is good practice to make the actual working day agree as nearly as possible with the nominal working day. To do so maintains an air of vigor in the administration of operations which is valuable. Moreover, a close agreement between the actual working day and the nominal working day forces a careful and a constant attention to time losses, which, in the long run, saves a great many hours that otherwise might be wasted.

Effect of Length of Day on Production Cost.—Of course, as a matter of business, it is perfectly obvious that the closer the actual working day approaches the nominal working day, the greater the daily production will be. If men are hired on a 10-hour basis but allowed to go to the work morning and noon on working time, required to wait around 15 minutes twice a day while the mixer is being started, and perhaps allowed to "ease off" toward quitting time at night, it is easy enough to convert what nominally is a 10-hour day into what actually is an 8-hour day. But if this is done, production will be correspondingly reduced, and the unit labor cost of the work accomplished will be correspondingly increased. This is unavoidable. Economy in operation therefore suggests that if men are hired to work 10 hours a day, operating practices should be so adjusted that 10 hours' work will be obtained. To work in any other way merely increases cost without developing any compensating return. Table I shows the number of hours' work done on a number of projects during July, 1925. These projects were in the same region and subject to about the same climatic conditions. The difference in the number of hours lost from other causes than rain and wet subgrade shows how important this matter may become. Probably the men were not paid for all of the time lost

TABLE I.—MIXER OPERATION ON SEVEN JOBS

July, 1925

Job number	Mixer operation during working days					Total hours mixer operated	Total hours mixer idle	Length of working day, hours	Average number hours worked per available working day	Average hours work done during days mixer worked	Total hours lost because of rain and wet subgrade	Total hours mixer lost from other causes than rain and wet subgrade
	No work	Worked less than 5 hours	Worked 5 to 10 hours	Worked 10 hours or more	Total days mixer worked							
1[a]	1	1	11	14	26	232	65	11	8.6	8.9	23	42
2[a]	4	2	13	8	23	209½	87½	11	7.8	8.6	17½	70
3[a]	1	3	6	17	26	225	45	10	8.3	8.7	18	27
4	3	2	8	13	23	212½	74½	10 to 13	8.2	9.2	46	28½
5[a]	7	2	16	2	20	155	142	11	5.7	7.75	22	120
6[a]	5	3	19	0	22	165¾	104¼	10	6.1	7.5	..	104¼[b]
7	5	1	10	10	21	187	99	11	7.2	8.9	10	89

[a] One Sunday worked.

[b] Weather losses not reported.

on the worst-managed jobs, but even if they were not, overhead, equipment depreciation, full-time men, camp costs, etc. continued to generate either direct or indirect cost. In short, any loss of working time involves some expense, which, in turn, increases the unit cost of the work. Taking the paving field as a whole, the matter of working time lost through lax management is one of the most conspicuous items of avoidable expense. Determining in advance the job practices which will be permitted and, on this basis as viewed in the light of past experience, the number of hours work which will be done per working day establishes a basis of performance which will avoid most of these losses and will correspondingly improve cost.

The Rate of Production.—Another decision which affects all of the plans for production is as to the rate at which production will be prosecuted. A first-class five-bag paver can turn out 48 batches (this matter is discussed in detail on pp. 175 to 180) of concrete an hour (based on 1-minute mix). Practically the same rate of output holds for three-bag pavers and for the first-class six-bag machines. Perfect performance is all but impossible of attainment over any extended period. On the other hand, "Do the very best you can" is no basis for job control. Indeed it is little better than "carte blanche" to do merely what happens to be comfortable or convenient. The selection of a rate of output may be high, as 45 batches an hour, or it may be low, but it should be specific, for it is only in this way that a standard of control can be set up and the responsibility of those who will be in charge of production can be established.

It may seem that a high standard of production should always be selected, particularly as the cost of labor per unit of pavement laid rises as production falls, but while it is true that under all ordinary circumstances a high rate of production will be desired, occasions arise when, for instance, the available equipment forces a choice between the acceptance of a low rate of production and the purchase of additional equipment. Under such circumstances, the choice will, at times, be in favor of a low rate of production.

The product of the number of hours' work to be done per day and the number of batches to be turned out per hour gives the production per day. It is the business of those who plan the work to see that, in every detail, the plans are such as to make the attainment of this output possible. In other words, having

TABLE II.—ORGANIZATION AND EQUIPMENT

One superintendent, $80 a week
One general foreman, $50 a week
One timekeeper, $30 a week

Major equipment	Number	Kind, size, etc.	Number		Rate pay
Receiving and loading material					**Persons employed 9**
Cranes	1	Koehring heavy-duty, No. 1, gas, ¾-yard	1	Operator	$ 8.00
Hoppers	2	Blaw Knox, steel hopper	1	Operator	3.00
Cement warehouses	1	Capacity 10,000 sacks	5[a]	Cemant handlers	3.50
Sack baler	1				
Sack cleaner	1	Electrically driven	1	Baler operator	3.00
			1	Foreman	5.00
Total daily labor cost of handling materials					36.50
Delivery of material					**Persons employed 4**
Trucks[b]	30	Single-batch, hired	30[c]	Drivers (owners)	
			1[c]	Truck foreman	
Truck	1	Light, miscellaneous work	1	Driver	3.50
			1	Checker	2.75
			2	Truck dumpers	3.00
Total daily labor cost of material delivery (exclusive of hauling)					12.25
Fine grading					**Persons employed 9**
Subgraders	1	Lakewood (new)	1	Foreman	7.00
Blade graders	1	8-foot Russell			
Rollers	1	Buffalo-Springfield, 3-ton	1	Roller operator	5.00
Fresnos	2	4-foot			
Teams	3	4-up plow; two, 3-up fresnos	3	Teamsters	3.00
Subgrade plow	1		1	Plow holder	4.00
Tractor	1	Caterpillar, 5-ton	1	Tractor operator	5.00
			2	Pick and shovel men	3.00
Total daily labor cost of fine grading					36.00
Setting forms					**Persons employed 8**
Forms	..	1,500 rod-feet, road rail	3	Form setters	3.00
Teams and wagons	1		1	Teamster	3.00
			3	Laborers	3.00
			1	Channel digger	3.00
Total daily labor cost of setting forms					24.00
Mixing and placing					**Persons employed 6**
Mixer	..	Koehring, 27-E,	1	Operator	6.00
			2	Puddlers	3.50
			1	Side spader	3.00
			2	Steel-joint setters	3.00
Total daily labor cost of mixing and placing					22.00
Finishing					**Persons employed 3**
Finishing machine	1	Ord	1	Operator	4.00
			2	Hand finishers	3.50
Bridges	2				
Belts	1	Bow-belt			
Floats	2	Cross-floats, long-handled			
Trowels, edgers, etc.					
Total daily labor cost of finishing					11.00

[a] These men also load cement onto trucks.
[b] Subcontractor's hauling equipment.
[c] Subcontractor's men.

TABLE II.—ORGANIZATION AND EQUIPMENT—(*Continued*)

Major equipment	Number	Kind, size, etc.	Number		Rate pay
Curing					**Persons employed 9**
Burlap, length, feet.....	..	1,500 road-feet	2	Laborers.....	$ 3.00
			6	Shovel hands.....	3.00
			1	Sprinkler.....	2.50
Total daily labor cost of curing.....					26.50
Water supply					**Persons employed 4**
Pumping units.....	1	C. H. & E. triplex gas.....	1	Pumpman.....	4.00
Pipe, length, feet.....	..	20,000 feet, diameter 3 inches.....			
Hose, length, feet.....	..	500 feet, mixer 2-inch.....			
			3	Pipeline laborers.....	3.00
Total daily labor cost of water supply.....					13.00
Miscellaneous					**Persons employed 2**
Watchman.....			1	Watchman.....	2.50
Private telephone line...	3	Branches, mixer, yard, and pump.	1	Water boy.....	2.00
Total daily labor cost of miscellaneous items.....					$4.50

Grand total labor (Exclusive of subcontractors' men)..... 54
Total daily payroll (Exclusive of salary of superintendent, general foreman, and timekeeper)..... $185.75

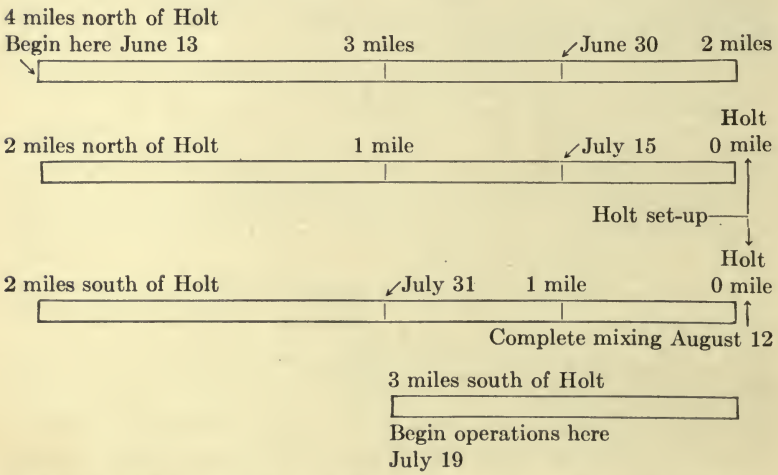
thus established a standard of output, every aspect of the work—the personnel, the equipment, the material supply, the order in which work will be prosecuted, etc.—must be worked out to validate this rate of production.

Facilities, Equipment, and Personnel.—The production rate which is selected, when viewed in the light of the methods to be used, will govern the facilities which are required, the rate of material delivery, and the equipment. The equipment, in turn, practically dictates the personnel. No construction plan is complete until the capacity of such facilities as sidings, storehouses, the machine shop, camps, etc. is determined on the basis of the rate of production which is to be maintained. It is, perhaps, needless to add that the very idea of a rate of production implies equipment and personnel to handle it. Therefore the plans for the job cannot be considered complete until the equipment which will be used is determined and the labor set-up is made. The wages which will be paid must also be determined. It may be added that the equipment and personnel set-up should be subdivided as the job itself is subdivided. This is desirable, as it then becomes possible for the head office to trace any divergence between plans and performance to its exact location and readily to determine whether or not the divergence is to be accepted. Table II gives a typical labor and equipment set-up

in the form which should be used in planning construction work. The desired production per hour and the assumed number of actual working hours, as defined in previous paragraphs, are shown on the job schedule, Fig. 1. Table III gives the actual results secured on a job where a high rate of production per hour and a high average number of hours' work per day were maintained.

JOB SCHEDULE, JOB 146

Length of job, 7 miles.....	Location, Holt, Nebr.
Enter location, June 13.....	Begin pouring, June 20
Average working day, 9 hours.....	Weather losses per month, 30 hours[a]
Production rate, 46 (five-bag) batches.	102 feet per hour, less 2 per cent probable underrun, 100 feet per hour



[a] Weather losses will vary with the season of the year and with the region in which work is to be done. For summer conditions in Middle West allow 15 hours lost time per inch of rainfall. For Eastern conditions allow 20 hours lost time per inch of rainfall. For spring and late fall add 5 hours per inch to these allowances.

FIG. 1.

The Points from Which Work Will Be Prosecuted.—Another decision which must be made is as to the points from which work will be prosecuted. Often this decision cannot be made until a good many factors such as sources of material supply, freight charges, cost of moving the material-handling plant, cost of hauling, etc. are thoroughly examined. The basis on which this decision rests will be developed in the chapters on hauling,

TABLE III.—PRODUCTION RECORD, CONCORDIA, MO., AUGUST, 1925

Standard 18-foot Pavement

Ross Construction Company, Kansas City, Kan., Contractors

Henry Kleifeld, Superintendent

Date, 1925	Hours worked	Lineal feet laid	Average feet per hour	Weather remarks
Aug. 1	10	972	....	Fair and warm
Aug. 2	10	990	....	Fair and warm
Aug. 3	5	503	....	Cement low
Aug. 4	10½	1,057	....	Fair and warm
Aug. 5	10½	1,088	....	Fair and warm
Aug. 6	10	1,000	....	Fair and warm
Aug. 7	5½	499	....	Rain in a.m.
Aug. 8	11¼	1,151	....	Fair and warm
Aug. 9	6½	614	....	Move to Sec. B
Aug. 10–13	....	.....	....	Move to Sec. B
Aug. 14	7	400	....	Fair and warm
Aug. 15	11¾	1,129	....	Fair and warm
Aug. 16	10½	907	....	Fair and warm
Aug. 17	Idle	.....	....	Rain
Aug. 18	10½	980	....	Fair and warm
Aug. 19	10½	989	....	Fair and warm
Aug. 20	Idle	.....	....	Rain
Aug. 21	Idle	.....	....	Wet subgrade
Aug. 22	10½	990	....	Fair and warm
Aug. 23	10½	985	....	Fair and warm
Aug. 24	10½	1,071	....	Fair and warm
Aug. 25	10½	1,056	....	Fair and warm
Aug. 26	10½	1,023	....	Fair and warm
Aug. 27	11½	1,089	....	Fair and warm
Aug. 28	10¾	1,068	....	Fair and warm
Aug. 29	10½	1,060	....	Fair and warm
Aug. 30	9½	906	....	Move Barber Green
Aug. 31	10½	1,006	....	Fair and warm
	234¾	22,533	95.9	

but it may be remarked here that, as this decision controls the amount of hauling to be done, and as hauling is an outstandingly expensive operation, an unfortunate decision as to the points from which work will be prosecuted may cost thousands of dollars. It is one of the matters requiring most careful investigations, and so much money may be lost by an improper selection of the points from which the work is to be prosecuted that, wher-

ever alternative arrangements are possible, it is good practice to calculate the hauling cost which will result from each arrangement before a final decision is made.

The Job Schedule.—The rate of production and the points from which work is to be prosecuted, the personnel, the equipment, etc., having been determined, it is possible to schedule production. No better nor more effective job control exists. The schedule should show, for each week-end or other convenient time interval, the point to which work should have been completed. Naturally a correction should be made for bad weather, and, at appropriate points in the schedule, allowance also should be made for the time required in moving, but no other allowance for lost time should be considered, as those incident to job practices, to accident, or to other unavoidable causes are assumed to have been dealt with when the number of production hours per day was established. With a schedule of this sort, administrative control can be made very rigid, for production which is below schedule can be due only to a low rate of output or to a failure to work the proper number of hours. In either case the cause can be determined readily and accurately. A typical job schedule in graph form is shown in Fig. 1.

The Value of the Job Schedule.—It would be difficult to lay too much emphasis on the value of a job schedule as a basis for both job control and administrative action. As a basis for job control, it provides the yardstick against which production should constantly be checked. But before it can safely be used for administrative action, it must be established beyond question that any failure to maintain the production schedule is properly to be laid to job management. Low production resulting from faulty operation of the mixer, to use an illustration at random, is a matter for which the job management is responsible. The superintendent should see and should correct such a condition, but responsibility for low production which is due to inadequacies in the mixer itself belongs to the man who sent the mixer out to the job or perhaps to the man who purchased it. In the same fashion, low production due to improper operation of the trucks rests squarely on the shoulders of the job superintendent, but low production due to a failure to provide an adequate supply of trucks lies with the men who prepared the construction plans.

No job should be undertaken without a job schedule. Moreover, the schedule should be enforced. A good deal of careful

discrimination is required in the assignment of responsibility when production is low, but if it becomes definitely apparent that there is a real lack of the managerial ability which is necessary for the maintenance of a carefully developed production plan, it is well to lose no time in looking for a superintendent of greater capacity.

Proper Basis of Cost Accounting.—It may not be out of place to add here that the plans for construction, when properly worked out, offer the only sound basis for cost accounting which has even been devised. The cost of a concrete pavement can vary from the estimate at only a limited number of points. The price of material can fluctuate or the yield from the materials used can vary from that assumed in making the construction plans; the rate of production may differ from that planned, the number of hours worked per day may not be as expected, the number of men employed may change, or the wage scale may vary. It is not the purpose of this book to discuss cost accounting, but it may be remarked that the expression of the probable cost of concrete in some unit, as for instance, $2 a square yard, tends to cover in a single item so many variables that its usefulness as a job control is apt to be lost. Effective job control rests first on the establishment of definite standards of performance in each of the fields in which results can vary, and then in the collection of specific data on whether these standards are being met. This book is not particularly concerned with the cost of material, because the responsibility for securing the materials does not rest on the job management. The job management, however, is interested in yield and of course in all of the other variables enumerated. The general purpose in planning is to reduce all of these matters to a specific statement, as, for instance:

Cost of materials, per batch	$5.75
Yield per batch, 4.50 square yards less 2 per cent	
Hours production per day, 9	
Rate of production per hour, 46 batches	
Number of men on payroll, 56	
Daily payroll expense	$220.00

The schedule shows the job superintendent in advance what he must do in order to validate construction plans. As long as the job schedule is maintained with the allowed personnel, and the proper yield per batch is secured, the cost cannot be far from correct. But if the schedule is not being maintained, it is neces-

sary that the cause be determined at once as completely and as accurately as possible, and it is good policy to keep the collection of data on performance on such a basis that a ready comparison can be made between plans and performance. Thus, suppose that as compared with the planned performance listed above, the actual performance has been as follows:

Cost of materials, per batch	$5.65
Yield per batch, 4.30 square yards	
Hours production per day, 9	
Rate of production per hour, 40 batches	
Number of men on payroll, 60	
Daily payroll expense	$230.00

In a case of this kind it is apparent that there is a good deal of divergence from the production plans, but in spite of this the contractor will know where to put his finger on it. This is the purpose of job reports—to show the head office where there is trouble before it is too late to correct it if it is, in fact, correctable. But this is cost accounting and so of no particular interest here, for while it is the business of the job superintendent to validate the construction plans, it is hardly his business to develop the report systems by which the head office ascertains that these plans are being validated.

CHAPTER II

PRODUCTION MANAGEMENT

There is a widely accepted impression that the principal element in effective production management is the energetic and intelligent direction of labor. Indeed this is not only accepted as a fact by men who are wholly unfamiliar with management but it is a widely accepted impression among many who have constant contact with management problems. Yet the slightest scrutiny of this impression of management will reveal the unescapable fact that if the direction of labor is the most important element in management, it must be true that methods, practices, procedures, the elimination of waste, the arrangement of the work, etc. are of less importance in expeditious and economical accomplishment than is brute strength. Put in a little different way, if the popular conception of a good manager as a man specially fitted to direct men is correct, it must be true that the proper direction of the men is the outstanding element in economical production. To those who hold this astonishingly fallacious view, the assertion that nothing could be much farther from the truth is likely to seem little short of heresy. Yet this literally is the case. As an element in successful management, unusual ability in handling men is of great importance only when other phases of management are so completely ignored that every attempt at increased efficiency becomes merely an effort to secure greater exertion on the part of the laborers. There are jobs where some improvement can be had in this way, but taking the highway field as a whole, the improvement in production which can be had by driving labor is small as compared with the improvement which can be had if management will frankly face its responsibility to think for the work it controls and, by correct thinking, will coordinate the activities which should be coordinated and will eliminate waste—in short, through the proper arrangement of all of the elements of the organization, will make high production possible.

Coordination.—Viewed from this standpoint, production management is a constant analysis of processes and practices, a constant study of relationships within the job itself, and a constant effort to coordinate activities and to eliminate waste. A concrete paving organization is not to be correctly viewed as a single organization. Rather it is to be viewed as a number of more or less independent organization groups, each charged with the performance of a specific task or tasks. The work of these groups is related, but, while the product of the organization as a whole is concrete pavement, the specific product of one group will be measured batches, of another, prepared subgrade, of another, batch-miles of material delivered, etc. Moreover, without any regard at all to the amount of physical effort developed by the men, if, for instance, an inadequate number of batches are measured and loaded by the group charged with the responsibility of performing this task, the amount of finished concrete which is produced will be equally inadequate. In exactly the same way, if the number of batch-miles produced by the group responsible for material delivery is low, a proper production of finished concrete cannot be maintained. The same holds for every operation in the production series, a fact which leads unavoidably to the conclusion that the first function of management is the development of coordination throughout the organization. On a concrete paving job the mixer is the key producer. It must, therefore, set the pace for the job. Coordination is merely the regulation of the production of the subordinate and related production groups to the speed of the key producer. Concrete cannot be mixed today and finished next week. Neither can the batches for tomorrow's work be measured today. As the batches are measured, they must be loaded. As they are loaded, they must be hauled. As they are delivered, they must be mixed. As they are mixed, they must be finished. The whole process is one of consecutive operations performed in a well-defined order from the delivery of the materials at the yards to the completion of the pavement. It naturally falls to the job management to see that each of these consecutive operations is so worked out that both in rate of production and in consistency of operation it harmonizes with the key producer. This is the essence of coordination, of synchronization, in the construction of concrete pavement.

Correct Rates of Production.—But synchronization is only one of the responsibilities of management. The manner in which equipment is operated may be improper. Indeed it commonly is improper. The next function of management is to seek out and to correct improper operating practices. A good mixer can, for instance, mix 48 batches of concrete every hour and still comply with all of the specifications which ordinarily govern a 1-minute mix. If the mixer operator can produce only 40 batches an hour, perfect synchronization cannot raise the production of finished concrete above that amount. Here again the popular concept of a manager as an enthusiastic, energetic leader of men fails completely. It is practically a certainty that the operator produces 40 batches an hour either because he does not know how to produce more or because personal physical, or mental limitations prevent faster operation. Enthusiastic leadership is no substitute for facts in a case of this sort. It is the plain duty of management to secure the facts and to act accordingly. If the operator does not know how to obtain full production, he should be carefully trained. This will take some time, but taking the time to correct improper conditions on a job is one of the important things which the superintendent is expected to do. Of course, if investigation shows that physical or mental limitations prevent correct operation, a new operator should be secured at once.

A similar condition is met on other parts of the job. The delivery of material may be in perfect harmony with the output capacity of the mixer, but if this is accomplished only by the use of 20 trucks where 15 should be able to do the work, it is the duty of the job management to locate the cause and to see that a balance between mixer output and material delivery is attained on the correct basis. Facts developed by careful analysis are needed before the situation can be corrected.

The number of these illustrations of the improper operation of equipment could be indefinitely extended, but this hardly is necessary in order to make it perfectly clear that efficiency in production not only requires that the rate of output of all of the elements in an organization be kept in harmony but also that this shall be accomplished on the basis of a correct rate of production from each equipment unit operated. This in its turn requires both the correct operation of the equipment units and their correct arrangement. It is not necessary at this point to discuss

the correct operation of individual units of equipment or their correct arrangement, as these will be developed in subsequent chapters. Rather the purpose is to point out that for each piece of equipment used on a construction job there is a rate of operation which harmonizes with the operation of other units of equipment and is correct for the job conditions prevailing, and that the arrangement of equipment, though not perhaps affecting the rate at which it can be operated, may materially affect the output of other units. To correct improper operation, particularly low production, it is, therefore, necessary not only to know both the rate at which each piece of equipment is operating and at which it can properly be made to operate, but also the effect of such factors as the arrangement of other equipment on the rate of operation. To obtain a high degree of efficiency through production management, it is therefore necessary to subject rates of operation and equipment arrangement to constant, rather detailed study.

There are other factors which also affect rates of operation, as, for instance, in the case of trucks, where road conditions may materially influence the rate of travel speed, but while there are, on the whole, a good many such factors, they do not, as a general thing, constitute a serious problem in production management. Neither are they of such uniform occurrence as to justify more than a passing comment here. Rather they are to be regarded as matters which will be developed quickly enough if rates of production are being subjected to careful study, when they can be handled as conditions of the moment require.

The Elimination of Unsound Methods.—The third field of management is in the detection and elimination of processes that are basically wasteful. It is entirely possible to secure a high degree of coordination throughout a job with production at all points on a scale of high efficiency, the nature of the methods and practices which are in use being considered, even though more or less of the methods of construction, general job practices, not to mention details of operation, are basically inefficient. The mix may, for instance, be carelessly dumped, with the result that four laborers spread it with difficulty, whereas with dumping and distributing practices carefully worked out, the mixer operator fully trained as to this point, and the right kind of finishing machine properly operated, two men can handle this work easily. Another illustration might be drawn from the difficulty often had

in finishing the subgrade. Often extra men are employed to accomplish this expeditiously and to lay parting strip and reinforcing steel where this is used. The result is a hasty finish, usually attended by a little loss of mixer time, followed by a longer period in which little or nothing is done by the men in this group until the mixer moves again. The situation is easily corrected by moving the mixer more often and over a shorter distance and pouring toward the end of the boom. This has the effect of dividing the subgrade under the boom into two approximately equal parts, a completed area where concrete can be poured and an uncompleted area where the final treatment of the subgrade can be accomplished, parting strip placed and steel laid, the number of men assigned to this work being, by this process, reduced to the two or three needed to perform these operations while the forward area is being poured. There are, of course, many other matters falling in this same category which in its essence confronts the management with the very simple but very important question: Can the same result be obtained by the use of less labor or by the more steadily applied efforts of a smaller group, if operating practices are somewhat modified? It is this aspect of production management which requires the extended discussion of methods and practices which is found in subsequent chapters. The objective of production management is the lowest possible construction cost. This in turn requires the use of the most economical methods and practices. When there is complete coordination between the various elements that make up a paving organization, when proper rates of production are maintained throughout, and the most economical methods and practices are in force, a high rate of efficiency cannot fail to result. It is the object in this and subsequent chapters to show how this condition can be brought about.

Training the Men.—A fourth aspect of management is its duty in the proper training of the individual laborers. Laying a concrete pavement has become almost completely mechanical. Labor is employed on or about the various machines which do most of the heavy work, and the amount of effort which most of the men are called on to put forth is governed by the rate at which these machines are operated. As a matter of fact, the effort required is, in some cases, so low that neither strength nor training is required in order to render satisfactory service. The operation of a good batch-measuring or batch-weighing device

offers an illustration in point. But on and around more of the machines, while the work can be done by good healthy men without much training, the burden placed on them when production is high is considerable. Men like to work under the direction of a man who knows his business. The very fact that he can put his finger on a trouble which they sense but cannot define adds greatly to their confidence in him, and their response is ready and wholehearted. On the other hand, men do not take kindly to petty interference with their pet ways of doing things; so the problem of taking unnecessary strain off the backs of the men themselves is apt to involve more tact than the solution of problems in the other fields which have been discussed. This fact should not, however, lead superintendents to overlook their responsibility here, for, if performing an operation in one way requires less time or less effort than must be expended in performing it in some other way, the efficient operation should be introduced, and each man, as new men are employed, should be carefully instructed as to just what to do and just how to do it. The objective is to bring the men through the necessarily hard day's work as fresh as possible. Men who are tired out may maintain production, but quality is apt to suffer.

The Basis of High Production.—No special gift in handling men is required in any of these phases of management. They involve merely the collection of data from which the facts as to conditions prevalent can be correctly determined and an attitude of entire willingness to act on the facts once they are determined. It is not desired through this method of presentation to leave the impression that those qualities which make for the forceful and effective direction of men are valueless in production management. They are quite as much an asset here as they are in other managerial positions. Such qualities tend to create confidence and to stimulate the men to cooperate in the improvement of production, but as valuable as cooperation is, production in the concrete paving field is not based largely on cooperation. Rather it is based on coordination, on knowing and maintaining proper rates of output, on the use of proper methods, and on the elimination of waste effort and lost time. All of these things require an intimate knowledge of the job in hand which no ordinary superintendent has the time to obtain on the basis of his own unaided efforts. He may know that production is low, but it is likely to take some hours of careful investigation to ascertain

the exact cause of this, to say nothing of learning the exact effect of each of the elements responsible for this underproduction. To continue the illustration, it may be apparent that an inadequate truck supply is responsible for some of the loss, but how much? It will take time to learn this accurately. Some of the trouble may be caused by poor operation of the mixer itself, but again how much? And if this is corrected, what will be the effect on the material delivery which already appears to be inadequate?

If an effort is made to build up production on the basis of a general knowledge of causes, some progress can be made, but at best it is a poor practice. Facts rather than generalities are the proper tools with which to work. When the superintendent knows that the hourly production of the mixer is only 64 per cent of what it should be, that therefore 36 per cent of the working time is being lost, that the time lost waiting for trucks accounts for 20 of this 36 per cent, that a failure to start the skip at the right time accounts for 10, and that the method used in handling the cement accounts for 6, he has at his disposal the facts which enable him to meet the situation promptly, exactly, and effectively.

Measurements of Time the Basis of Effective Management.—The work of obtaining the facts is rather an elementary task, but it requires a good deal of time and patience. Engineers and contractors alike are familiar with making measurements. It is, therefore, somewhat surprising to find that there is so little use made of the simple principle of measurement in management as applied to highway work. The engineer measures the length of a board without giving the fact that he has measured it a thought, but often he would hesitate to take out a stop watch and measure the time used in nailing it in place! There is, however, no reason in such an attitude. It would not be one whit more grotesque to attempt to build a house without a rule on the job than it is to attempt to build up an efficient production organization without a stop watch. Indeed it is not going too far to say that it is totally impossible to build up top-notch production, to couple this with real efficiency throughout the organization, and to eliminate waste in time and effort unless the time elements involved in all of the phases of production are subjected to constant measurement. This does not mean that the superintendent will spend his time taking stop-watch readings on performance, though once he is accustomed to using a stop

watch he is likely to make as much use of it as he does of his rule, checking the job here and there as conditions seem to him to require. Rather it means that he should have at his disposal younger assistants who give most of their time to making such readings, developing in this way the facts which he needs in the management of production. The following schedule of stop-watch studies covers the items which have been found to be of most importance in analyzing concrete paving work.

Mixer Operation.—Two stop-watch studies should be made daily, one in forenoon and one in the afternoon, each of 1 hour's duration. During these studies the mixing cycle should be carefully timed and all delays or interferences recorded as to both length and cause. Full notes should be made of general operating conditions, and any unusual conditions should be fully described. All readings and notes should be made in the field. Nothing should be left to memory. Report on form in Fig. 2. The hourly studies should be summarized as on the forms in Figs. 7 and 8, and when so summarized, should show the average rate of production and the causes of losses of time at the mixer. These

STOP-WATCH STUDIES ON THE MIXER

Job number.....
State.....
County.....
Make of mixer.....Size.....Condition.....Date.....
Bags of cement per batch.....Drum revolutions per minute.....
Duration of study.....minutes

Mixing time, seconds			Mixing time, seconds			Lost time, seconds
Charge	Mix	Dis-charge	Charge	Mix	Dis-charge	
Totals						
Averages						

FIG. 2.—Front.

TRANSPORTATION CONDITIONS AT TIME STUDY WAS MADE

Average length haul, 0.01 mile.....Condition of road or track.....
Weather.....Number of trucks or trains in use during study.....

RESULTS ACCOMPLISHED DURING STUDY

Number of batches mixed.....Square yards of pavement placed.....
Yield in per cent.....

SUMMARY OF TIME LOSSES AND DELAYS DURING STUDY

Cause of loss	Time, seconds	Cause of loss	Time, seconds
Shortage of hauling equipment		Lack of materials at mixer	
Hauling equipment delayed		Lack of materials, batcher plant	
Switching, dumping, or turning		Handling cement	
Mixer trouble, mechanical		Subgrade not prepared	
Mixer trouble, operative		Setting parting strip	
Water supply		Placing reinforced steel	
		Waiting on finishers	
		Total	

Remarks:

Place.....Signature.....

FIG. 2.—Reverse.

causes of delay may then be subjected to further analysis through the studies made at the material yard, on the transportation, etc.

Once each day, either just before or just after one of the regular stop-watch operation studies, the number of revolutions made by the mixer drum should be counted for a period of 2 or 3 minutes in order to determine the average number of revolutions of the mixer drum per minute. Report on the form in Fig. 2.

A study of skip operation, covering a period of about 30 minutes, should be made at least once a week to determine time required (*a*) to raise skip from the ground to full elevation, (*b*) charging lag, or the time elapsing from the setting of the timer until all the materials have entered the mixer drum, and (*c*) the time elapsing from the instant the operator releases the lever until the skip reaches the ground. An effort should be made to secure

readings when the aggregate is wet and when it is dry, as well as when it is in ordinary condition, so as to show the effect of varying degrees of moisture in the material on the time required to empty the skip. This study enables the superintendent not only to check the set of the timer but to determine whether the engine on the mixer is operating properly. Make full notes and report on the form in Fig. 3.

Two or more studies of about 15 minutes' duration should be made each week on discharging the batch from the mixer. These studies should determine (*a*) the time elapsing from the sounding of the timer until the operator has opened the discharge gate so that concrete appears in the chute, (*b*) the time from opening the discharge gate until batch is discharged into the bucket, and (*c*) the time required to run out and dump the bucket. Of these studies, (*a*) indicates the efficiency with which the operator responds to the bell and (*b*) the condition of the mixer, mechanically. Make full notes and report on the form in Fig. 3.

Twice each week a study of about 15 minutes' duration should be made of the operation of the mixer water tank. These studies

STOP-WATCH STUDIES OF MIXER SKIP, DISCHARGE, WATER TANK, AND BATCHER

Job number.....
State.....
County.....

Reading	Mixer skip				Discharge			Mixer water tank						Batcher			
														Sand		Gravel or stone	
	Raise	Empty	Lower	Condition of materials	Open	Discharge	Empty bucket	Leakage into mix	Total supplied	Fill, seconds	Empty, seconds	Supply leakage	Grade effect	*a*	*b*	*a*	*b*
1																	
2																	
3																	
14																	
15																	
Total.....																	
Average..																	

FIG. 3.—Front.

NOTE: *a* equals time required to fill; *b* equals time to dump and return ready to load.

Remarks:

Crane Operations

Make.....Size.....Condition.....

Item	Car to bins		Car to stock		Stock to bins	
	Sand	Stone or gravel	Sand	Stone or gravel	Sand	Stone or gravel
Total time of study, minutes.....						
Time lost or idle,[a] minutes.....						
Number of buckets handled.....						
Cubic yards handled.....						
Average cubic yards per bucket.....						
Observed rate, cubic yards per hour...						
Rate per hour, net time.....						

Subgrade, Forms, and Curing

Item	Preparing Subgrade	Setting forms	Parting joints		Expansion joints		Handling burlap	Covering concrete[b]	Sprinkling	Placing reinforced steel
			Setting	Beading	Setting	Beading				
Total time of study, minutes.....										
Time lost or idle,[a] minutes.....										
Number men employed..										
Work done.....										
Unit in which given.....	Square yards	Linear feet					Square yards			Square feet
Average observed rate per hour.....										
Rate per hour, net time..										

[a] Give causes and amounts below.

[b] Average depth.....inches.

Remarks:

Date.....

Place.....Signature.....

Fig. 3.—Reverse.

should include (*a*) a careful observation as to whether there is any leakage into the mixer drum when the valve is supposed to be closed, and if valves are leaking, a measurement of the leakage should be made; (*b*) five readings on the time required for the tank to fill; and (*c*) five readings on the time required for the tank to discharge into the drum. Of these, (*a*) indicates the condition of the mixer and (*b*) of the water supply. Make full notes with sketches if necessary and report on the form in Fig. 3.

A daily record should be kept of the number of men employed to perform each of the various operations. The right-hand side of Table 2 gives the general style and arrangement of this record. A record should also be kept of the progress of the work done, the time lost by the mixer, and the cause of such delays. At the end of each week a report should be made of the men employed in each of the various operations during each working day, the daily production, and the time losses during each day of the week. The purpose of this record is to show how closely

WEEKLY PRODUCTION REPORT

Job number.....
State.....
County.....

Date	Number trucks or trains in use	Average haul 0.01 mile	Condition of road or track	Weather	Length working day, hours	Total loads or cars delivered	
						Aggregate	Cement
Average.....				Total....			

Date	Number of hours crane worked	Cars unloaded	Number hours mixer crew on job	Number batches mixed	Square yards of pavement placed	Total number men employed on job
Total.....						

NOTE: This form must show the work for each day during the week.

FIG. 4.—Front.

SUMMARY OF LOST TIME OR MAJOR DELAYS, HOURS

Date	Hauling equipment		Mixer trouble	Water supply	Lack of subgrade	Lack of materials at yard	Batcher or crane trouble	Joints or steel	Moving	Rain	Wet subgrade	Cold	Miscellaneous
	Supply	Operation											
Total.....													

NOTE: Only stops or delays of 15 minutes or more each should be included on this report and recorded in hours to one decimal place. Stops of less than 15 minutes each are only reported for the periods during which stop-watch studies are made when all delays are recorded in seconds regardless of length. The cause of any large or persistent time losses reported under "Miscellaneous" should be given under "Remarks."

Remarks:

Place.....

Date.....Signature.....

FIG. 4.—Reverse.

the scheduled number of men used on each operation and the scheduled number of hours' work per day is being approached and where the cause of any failure to meet the schedule lies. Report mixer operation and lost time on the form in Fig. 4.

Handling Materials.—Studies at the material yard should be made to determine as nearly as is possible under prevailing operating conditions (*a*) the output capacity of each major piece of equipment, (*b*) the output capacity of the plant as a whole, and (*c*) the efficiency rate at which operation is conducted. The details of these studies will vary with the layout of the plant and the equipment used. Where some form of crane or similar equipment is used to unload the material from cars and to supply the bins serving the batchers, a series of stop-watch studies should be made to determine the operating characteristics and performance ability of this equipment, as to (*a*) time required to handle respectively a bucket of sand and stone or gravel from car to bins, from car to stock pile, and from stock pile to bins, and (*b*) the average amount of each of these materials handled per bucket for each of these operating conditions. During these studies all

delays or time losses should be carefully noted and recorded as in the mixer stop-watch operation studies. In determining average load per bucket for the different materials and under varying conditions as well as the average loading time, it will be necessary

STOP-WATCH READINGS FOR CRANE OPERATION

Job number.....State.....County.....

Date.....Number of { Trucks or Trains } used.....Haul, 0.01 mile.....

Condition road.....

Working time				Working time				Lost time or delays
Load	Swing	Dump	Return	Load	Swing	Dump	Return	
Totals.....								
Averages.....								

Number bucket loads handled during study.....

.....Quantity, in cubic yards of truck loads handled.....Duration study, minutes...

FIG. 5.—Front.

SUMMARY OF TIME LOSSES, SECONDS

Cause of loss or delay	Time	Cause of loss or delay	Time
Hauling equipment, supply.....		Rain.....	
Hauling equipment, operation.....		Wet grade.....	
Moving crane.....		Operator.....	
Engine trouble.....		Checking grade.....	
Shovel repairs.....			
Cable repair.....			
Water or fuel.....			
Rocks, stumps, or roots.....		Totals.....	

Place.....Signature.....

FIG. 5.—Reverse.

that some of the studies shall be of sufficient length to include the unloading of an entire car so as properly to distribute the effect of the smaller loads and longer loading time when the car is nearly empty. Quantities handled from stock piles can usu-

ally be determined by noting the amount of material in the bins when the study begins and ends, together with a count of the number of batches drawn out. Full notes should be made and the data reported on the form in Fig. 3 together with such comments and explanations as may be necessary.

Whenever time permits, a series of more detailed studies, each of 1 hour's duration, should be made of crane operation. These studies should show (*a*) time required to load bucket, (*b*) time required to raise bucket and swing boom, (*c*) angle through which boom is swung, (*d*) time required to dump bucket, and (*e*) time required to return ready to load. Report these studies with notes on the form in Fig. 5.

Detail studies should also be made of the operation of the batcher. Frequent studies, each of about 15 minutes' duration, should be made, preferably when full hauling equipment is available, to show (*a*) the time required to fill batcher with each of the materials and (*b*) the time required to dump batch and return batcher ready to load. Report on the form in Fig. 3.

When mechanical loaders or conveyers are used, the same general procedure will be followed with such modification of details as conditions may require. Thus for belt conveyers the item to be determined is the number of cubic yards handled per hour in unloading sand, gravel, etc., from car pits to stock pile and the time losses or delays encountered. For mechanical loaders the study will determine the time required to fill the batch box or measuring device and to discharge it, studies being made in the same general manner as for the batcher plant.

Once a week, or oftener, 1 hour's study should be made of the operation of hauling equipment in passing through the material plant. These studies should show the time required for each operation, that is, loading the sand, coarse aggregate, cement, etc., as well as the total time consumed by each transportation unit studied from the time it crosses a fixed line at or near the entrance of the yard until it crosses a line at the exit. These should be stop-watch studies tracing the vehicles completely through the yard and including in the record all waits, stops, or delays of whatever nature. These studies will develop the efficiency of operations in the material yard and will suggest desirable modifications in yard layout. Report on the form in Fig. 6.

The studies of the operation of the hauling equipment through the material yard cover, of course, only a part of the hauling

STOP-WATCH STUDIES FOR HAULING

Job number.....State.....County.....
Equipment, kind and make.....Size.....Condition.....
Condition of road.....Date.....

Number given vehicle	Size of load	Haul 0.01 mile	Time in seconds								
			Load	Haul	Waits or delays	Turn or switch	Unload	Return for load	Turn or switch	Waits or delays	Total round trip
Totals.....											
Averages.....											

FIG 6.—Front.

STOP-WATCH STUDIES FOR HAULING

Duration study.....min.

Number given vehicle	At material yard						At mixer					On road			Total round-trip time
	Turn or switch	Waits or delays	Loading			Total time in yard	Turn or switch	Waits or delays	Dump cement	Dump batch	Total time at mixer	Haul 0.01 mile	To mixer	To material yard	
			Sand	Stone or gravel	Cement										

NOTE: Record all time in seconds.

Date.....
Place.....Signature.....

FIG. 6.—Reverse.

cycle. They should be extended to show in a similar manner in ½-hour studies the operation of the hauling equipment at the mixer, including turning, backing, dumping cement bags if carried on the load, dumping the batch or batches into the skip, closing endgate, and getting under way and across a given line, including all waits and delays. The general procedure should be exactly the same as the vehicle studies at the material yard, each vehicle studied being traced through from crossing a line at or near the turntable until crossing the same line on its way back to the material yard. Report on the form in Fig. 6 with such notes and sketches as may be necessary.

Where an industrial railway is used, the above procedure need be varied only so as to show handling of batch boxes, switching cars, and switching trains.

A daily study on the travel rate of the trucks to give the time required to drive from the given line at the mixer to the material yard and *vice versa* should be made. Road speeds are apt to vary between rather wide limits with road conditions, etc., but for efficient operation should be closely controlled. As many opportunities as are available for the study of truck speed should, therefore, be utilized in securing road-speed data so as to obtain a really clear conception not only of the average speed but of the limits between which speed may be expected to vary and how frequent these variations may reasonably be expected to be.

Handling the cement is generally a series of labor-consuming operations and often the direct or indirect cause of considerable delay at the mixer. In addition to the already outlined studies, such additional data as may be necessary should therefore be secured and a complete record made of handling this material from the railroad car to the mixer skip. This report should show the number of seconds required per sack of cement for each of the following operations: (*a*) trucking cement from car to warehouse, (*b*) warehouse to batch trucks, (*c*) emptying bags on load at cement house, or (*d*) emptying bags at mixer.

The data given in Figs. 7, 8, 9, and 10 show conditions at the mixer before and after an effort to improve production on the basis of management along the lines discussed above. When coupled with the data given in preceding paragraphs, they indicate both the nature of the data which the stop-watch analysis of this job made available and the results that were had by using these as a basis for bringing production up to a higher standard.

SUMMARY OF STOP-WATCH STUDIES ON CONCRETE ROAD CONSTRUCTION. AS OPERATED BY CONTRACTOR

Date, 1925	Number of batches mixed per hour	Mixer cycle, time in seconds			Per cent of working day lost by mixer from following causes								
		Charge	Mix	Discharge	Insufficient truck supply	Truck delayed because of mechanical trouble	Mixer trouble mechanical	Mixer delay due to operator	Water-supply trouble	Preparing subgrade	Lack of material due to poor supervision	Delay due to concrete finishers	Miscellaneous delays
June 11	16	9½	59½	10	....	...	...	15	..	..	.....	50	
June 12	36	9½	61	10	....	...	...	10½	..	9			
June 12	31	9	60	12	....	9	...	16½	..	5			
June 15	36	9½	61	10	...	9½	...	6	2	1½			
June 15	34	9½	61½	10	....	5	...	13	6				
June 19	31	9	58	12	....	3	...	17½	..	5½	.....	7	
June 20	38	10	59	10	10	1	...	6	1				
June 20	38	10	59	10	6	...	...	8	2	1½			
June 20	31	9½	59	10	14	1	...	9	..	..	.....	..	9
June 25	10	10	61	10	13	21½	41½	1					
June 26	17	9½	61	10	28*	1	27½	1½	4				
June 26	24	9	60	12	39½*	...	...	4½	2				
June 30	20	9½	61	10	49*	3	...	3	1				
June 30	23	9	61	12	30½*	2	...	6	10				
Averages	27.4	9.5	60.1	10.6	13.6	4.0	4.9	8.4	2.0	1.6	.....	4.0	0.6

Mixer cycle 80.2 seconds

Mixer was idle 39.1 per cent of working day

Additional time lost due to slow operation of mixer, 60.9 − 57.1 = 3.8 per cent

Per cent of possible efficiency, 57.1 per cent.

* Very inadequate supply of trucks developed when hauling distance changed from 1 to 5 miles.

FIG. 7.

SUMMARY OF STOP-WATCH STUDIES ON CONCRETE ROAD CONSTRUCTION. AS OPERATED UNDER EXPERT PRODUCTION MANAGEMENT

Date, 1925	Number of batches mixed per hour	Mixer time, seconds			Per cent of working day lost by mixer from following causes								
		Charge	Mix	Discharge	Insufficient truck supply	Truck delayed because of mechanical trouble	Mixer trouble, mechanical	Mixer delay due to operator	Water-supply trouble	Preparing sub-grade	Lack of material due to poor supervision	Delay due to concrete finishers	Miscellaneous delays
July 27	45	10	64	3	.....	2½	1	.....	1				
July 28	44	10	64	2½	.....	5	..	.....	½				
July 28	43	10	63½	2½	.....	8½	..	.....	...	..	...	.....	½
July 28	44	10	64	2½	.....	½	..	.....	...	..	6½		
July 29	45	10	63½	3	.....	..	..	.....	4½				
July 29	46	10	64	2½	.....	2½							
July 30	38	10	64	3	.....	..	..	.....	2	4	13		
July 30	38	10	64	3	.....	3	..	.....	16[a]				
July 31	47	10	64	2½									
July 31	43	10	63½	3	.....	2	..	.....	1	5½			
July 31	46	10	63½	2½	.....	..	..	.....	2				
Aug. 1	45	10	64	2½	.....	..	..	.....	4½				
Averages	43.7	10	64	2.7	.....	2.0	..	.....	2.6	0.8	1.6		

Mixer cycle 76.7 seconds

Time lost by mixer, 7 per cent of working day

Additional time lost due to slow operation of mixer, 93.0 − 91.0 = 2.0 per cent

Per cent of possible efficiency, 91.0 per cent.

[a] Because of this time loss due to high pressure in line, water losses do not show improvement that was actually made.

FIG. 8.

The data shown in Figs. 7 and 8 were secured at the mixer, but data of this same general nature were collected on other operations as needed. The general style and arrangement of stop-watch studies given above was followed in this work, but

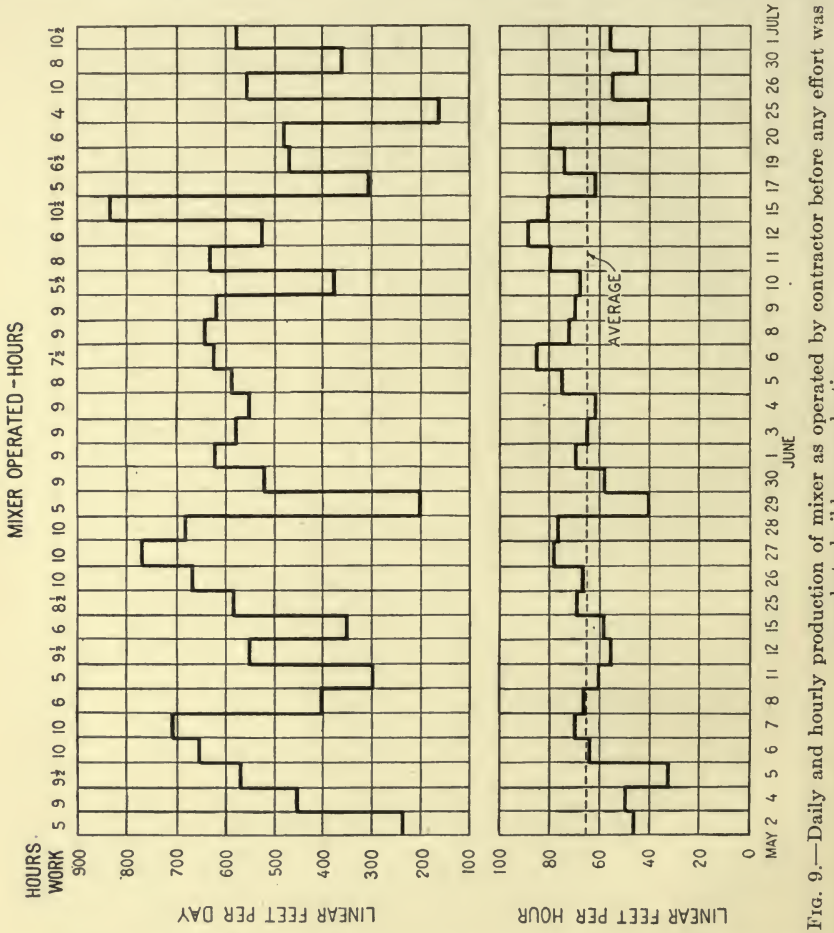


FIG. 9.—Daily and hourly production of mixer as operated by contractor before any effort was made to build up production.

the form in which data are collected is not of primary importance. It may, in fact, be varied to meet the needs of the particular situation at the moment under scrutiny or the preferences of those controlling the work. There will be no difficulty on this score if it is clearly understood that stop-watch readings are, after all, merely measurements and that to make them pitilessly effec-

tive it is only necessary to have a clear appreciation of just what it is that is to be measured and why it is to be measured, and then to continue the readings over such a period as may be necessary in order to develop the effect of variable factors that recur only occasionally.

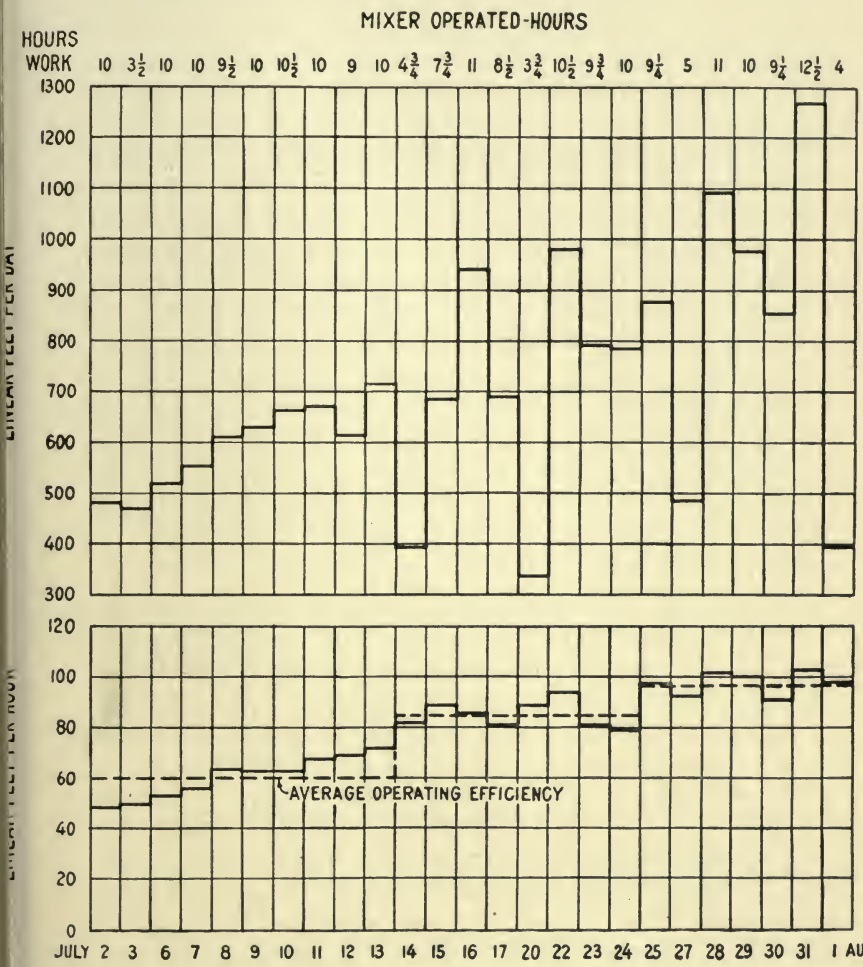


FIG. 10.—Daily and hourly production, same job shown in Fig. 9, during effort to improve production by coordinating equipment and correcting improper operating practices.

Stop Watches.—The actual work of taking the readings and of preparing summaries is not at all difficult. A good stop watch is required. There are a number of types of stop watch on the market. The standard type is so constructed that by pressing on

the stem the hand is released. Pressing the stem a second time stops the hand, and pressing it a third time returns it to the zero position. For many purposes such a watch is entirely adequate, but for reading successive time intervals over an extended period the standard type has been found to wear out rather rapidly. A better type for this work is one in which the hand is released by a lever on the side of the case; as long as this lever is in the release position, the mechanism which moves the hand remains in motion. The hand can be returned to the zero position at any time by pressing on the stem. Without further manipulation on the part of the operator, however, it begins at once to count time on the next operation. Watches of this type appear to wear better than standard watches, as is natural, since less manipulation of them is necessary. As far as the work of taking readings is concerned, either type is reasonably satisfactory. The standard watch is stopped before it is read. The type recommended must be read while it runs. This difference is not material except that there is a slight loss of time in stopping a watch to read it. This is of small consequence, for after the use of a standard stop watch has been pretty well mastered, the loss of time in manipulation and reading should always be less than ½ minute per measured hour. Since with the side lever release, however, the loss can rather more easily be kept within this limit, there is here also some advantage in its use.

The principal difference between these two types lies in the fact that the watches of the standard type wear out more rapidly on work of this kind and are difficult to repair except at the factory, for local jewelers are seldom familiar enough with stop watches to do satisfactory work. The type recommended has generally given satisfactory service, though the life of any type of stop watch subjected to work as severe as this is bound to be short.

Taking the stop-watch readings can be quite satisfactorily done by the young engineer just out of college, and for the contractor who desires to bring able young men into his organization for training and development, this work opens a training ground where they can, at once, be valuable to him and at the same time can learn more, both of management and of construction, than is possible in any place now open to them in the construction field.

Management Undermanned.—In closing this chapter, it may be appropriate to note that management in the highway construction field generally—and this applies to concrete paving

work as much as to other construction activities—is undermanned. The load placed on the job superintendent is too heavy. One of the reasons that the production standards are today so low is that too many details are thrown onto this one man. It requires time to think and to plan work, and if all of the available time is taken up in attending to the details of construction work, none is left for the careful analytical study of the job in hand. But without time for study and thought it is hard to improve ordinary conditions. The supervision of a modern paving job often involves directing operations costing from $250,000 to $1,000,000. This is quite a task. An overworked superintendent is no more likely to be an outstanding success than is an overworked laborer. The solution lies in giving the superintendent enough assistance so that he can handle his work without undue strain—enough help so that he can have time to think for his job. If he does not have this time, he becomes little more than a job foreman, and production settles back to the ordinary level.

Summarizing briefly the concept of production management which is here presented, it involves two things: securing proper production while work is being done, and so planning the job that the working time can be fully utilized. There is plenty of evidence that production today is less than 60 per cent of what it should be and that on most jobs the personnel employed exceeds actual needs. The field for management based on a careful analysis of performance on the job in hand, of the efficiency of the methods in use, of the adequacy of equipment, and of waste is, therefore, a large one.

CHAPTER III

PURCHASING AGGREGATE FOR YIELD

In concrete paving work the important materials are cement, coarse aggregate, sand, and water. Minor materials include reinforcing steel, parting strip, joint material, etc. Taken together, the materials which are used in a concrete pavement constitute the largest item in its cost. But they also constitute the most dependable item, for prices can be, and indeed often are, arranged even before the bid is made out. In a large organization matters of this kind would be attended to by the purchasing office, but as many of the organizations which handle paving contracts are too small to require a regularly organized department of this sort, the details incident to purchasing materials are more often looked after by the contractor and his superintendent. Purchasing materials is not, strictly speaking, a part of production management, but as some phases of this task are intimately connected with the cost of production and as the objective of production management is to secure a unit cost low enough to insure a reasonable profit, these will be discussed briefly, but no reference to purely purchasing problems and practices will be made.

Yield Should Affect Selection of Materials.—The amount of concrete, that is, the yield, to be had from the use of a given selection of materials can be predetermined with a relatively high degree of accuracy. But the cost of the concrete necessarily falls as the yield from the material used rises, if the cost per yard or per ton of material used is constant.

The general principle which is involved is simple. Concrete of the more ordinary proportions used in highway work is merely a dilution of mortar with whatever amount of stone the specification of the moment will permit. In concrete of this kind, there is practically always a surplus of mortar, that is, more mortar than is needed to fill the voids in the coarse aggregate. The amount of this surplus depends on the void content of the materials used. But if the surplus of mortar is large, the yield

will be relatively high, while if the surplus is small, the yield will be relatively low. As a general principle, then, the lower the void content is, the greater the yield will be, as current specifications are drawn, and therefore the lower the cost of the concrete. It follows naturally from this that the lower the void content of aggregate, the greater is its value to the contractor.

The Use of a Relatively Fine Sand.—Coarse sands, in general, produce the higher strength when used in making mortars, but sands which carry more nearly the minimum percentage of coarse particles named in the ordinary specifications produce a somewhat larger amount of mortar. Most of the specifications for concrete pavement now in force establish standards for the gradation of both sand and coarse aggregate, these being quite rigid and on the whole carefully enforced, but within the limits so established give almost no attention to the strength of the resulting concrete. There is, for this reason, no special advantage to be gained by the contractor from the selection of a coarse sand, whereas it is commonly true that the use of a somewhat finer sand will favorably affect the yield and, as a general thing, will improve workability. For this reason, as long as the current practice of using arbitrary mixes based on volumetric proportions persists, the contractor is likely to find it to his advantage to select a sand which is somewhat finer than is ordinarily recommended for concrete work, particularly if the maximum size of the coarse aggregate is from 1 to 1½ inches, for it is the common experience of those handling concrete in the field that, if coarse sand is used with well-graded coarse aggregate of this sort, a harsh mix is likely to result. A 1:2 mortar made by mixing a relatively fine sand with the proper amount of cement and just enough water so that it will be sufficiently workable to meet ordinary field requirements will yield about 2.2 cubic feet of mortar per bag of cement. A mortar of the same proportions in which a considerable amount of coarse sand is present may run as low as 2.1 cubic feet per bag.

Effect of Void Content on Yield.—Now, turning to the matter of coarse aggregate, it has been mentioned that as concrete mixes are at present specified, there usually is a considerable excess of mortar. Under such a condition the percentage of voids in the coarse aggregate becomes a matter of large importance, for it governs the amount of excess mortar which a given combination of materials will produce. Moreover, it will be apparent that

the greater the excess of mortar, the greater the yield will be. Now poorly graded coarse aggregate may easily have a void content that is in excess of 50 per cent, while a well-graded coarse aggregate may have a void content as low as 35 per cent. If the yield of concrete made from aggregate having these two extremes in void content is examined on the basis of a 1:2:4 mix, the following results will at once appear:

Case 1	Cubic Feet	Case 2	Cubic Feet
Coarse aggregate	4.0	Coarse aggregate	4.0
Mortar developed by specification requirements (fine-sand basis)	2.2[a]	Mortar developed by specification requirements (fine-sand basis)	2.2[a]
Voids in coarse aggregate content of concrete 50 per cent of 4 cubic feet	2.0	Voids in coarse aggregate content of concrete 35 per cent of 4 cubic feet	1.4
Mortar in excess of that needed to fill voids	0.2	Mortar in excess of that needed to fill voids	0.8
Measured coarse aggregate content	4.0	Measured coarse aggregate content	4.0
Yield[b]	4.2	Yield[b]	4.8

[a] The fine-sand basis is used in developing these illustrations because the most common maximum size for coarse aggregate is 1½ inches and with coarse aggregate of this maximum size, particularly if well graded, sands containing a large percentage of coarse particles should not be used.

[b] No allowance made in either case for water to wet coarse aggregate or for trapped air. A calculation on the basis used above is not strictly accurate from a technical standpoint, but the refinements necessary to make it so would complicate the presentation without materially affecting the result. They are, therefore, omitted.

Relative yield is obtained by dividing 4.8 by 4.2, which is 1.14+; thus to produce an equal yardage of pavement, a little over 114 batches of concrete must be used under the conditions given in Case 1 to each 100 which are needed under the conditions controlling Case 2.

But the batch is the basis of production on all concrete paving work. Indeed the production is in batches, and the rate of production depends on the number of batches that can be produced in a given time. Whatever reduces the size of the batch will then reduce the total output in square yards accordingly, for the fact that all of the batches are a little small yields no benefit of any sort which will tend to bring about the production of more batches. Production merely falls behind schedule by whatever amount the size of the batch is below standard, with the result

that the working time required for completing the job is correspondingly lengthened.

The Effect of Low Yield on Labor and Other Costs.—The cost of such a loss in production as this is rather easily calculated with sufficient accuracy to show the value of care in selecting materials. Thus the daily payroll on a concrete paving job of standard size is commonly not far from $200. Depreciation on equipment will amount to about half of this amount. Other items of expense incident to the operation of a paving plant will account for the expenditure of perhaps another $100 a day. So, in a general way, the daily cost of other items than materials should not be far from $400. But, as just noted, the number of batches which can be handled per day is in no way modified by such relatively small changes in their size as can result from the causes under discussion. It, therefore, is obvious that each per cent by which the yield falls below normal involves the dissipation of labor, equipment, and miscellaneous costs—values amounting to about $4 a day. This loss must, of course, be distributed over the average daily production by batches. For purposes of illustration suppose the daily production is 250 batches. Low yield, in such a case, causes the loss of money spent on labor, equipment, and related miscellaneous items to the amount of 1.6 cents per batch for each 1 per cent that the yield is low. It is, of course, apparent that if the average run is high—say, 400 batches a day—the loss from this cause will drop as low as 1 cent per batch for each per cent production is low, while if production falls to about 200 batches a day, this cost tends to rise to about 2 cents.

The Effect of Low Yield on the Cost of Materials.—Now, examining the effect of yield on the amount of material which must be used, it will be apparent that if the use of the specified measured amount of cement, sand, and coarse aggregate produces less than the standard amount of concrete, the total amount of material of each kind which must be used to complete the job as a whole will be increased accordingly. The following is illustrative of the effect of this where a 1:2:4 mix is used, a standard five-bag batch being assumed:

5 bags of cement at 60 cents	$3.00
10 cubic feet of sand at 6 cents	0.60
20 cubic feet of gravel at 9 cents	1.80
Cost of materials per batch	$5.40

Now, if the materials in a batch cost $5.40 but the batch yields less than the standard amount of concrete, it naturally follows that for the loss of each per cent in yield, within any limits ordinarily involved here, there is an increase of 1 per cent in cost, or, in other words, if the yield is but 99 per cent, 101 per cent of the standard number of batches must be used. The total loss per five-bag batch for each 1 per cent of extra material that must be used is then as follows:

Labor from about 1 cent to about 2 cents.
Materials seldom much under 5 cents, and seldom much over 6 cents.
Total loss 6 to 8 cents per batch for each 1 per cent of extra material required because the yield is low.

This is, of course, only a generalized treatment of the case and is used for the purpose of illustrating the importance of low void content to the contractor. An exact comparison of values on this basis is a more technical matter not of interest here.

The Effect of Yield on the Value of Coarse Aggregate.—Reverting to the difference in the amount of material required as between a poorly graded coarse aggregate and a well-graded coarse aggregate, it was shown that under the conditions given in the illustration used above the difference in yield amounted to a little over 14 per cent; so, in this case, the use of a poorly graded coarse aggregate instead of a well-graded coarse aggregate would actually have cost from 85 cents to $1.15 per batch. Moreover, in the illustrative example, the total difference in production was due to the difference in void content of the coarse aggregates, of which 20 cubic feet was assumed to be used per batch (1:2:4 mix). At this rate the difference in the cost of the concrete resulting from the use of these two coarse aggregates would amount to from about $1.15 to about $1.55 per cubic yard of the coarse aggregate used. In other words, as a matter of practical business expediency, a contractor could, in a case of this sort, afford to pay from $1.15 to $1.55 more per cubic yard for the well-graded coarse aggregate than he could afford to pay for the poorly graded coarse aggregate.

General Rule.—Naturally, as the purpose has been to illustrate the importance of differences in void content, a case showing a wide variation has been used. However, as between the various materials offered in any market there is quite apt to be enough difference in void content to make a study of this matter

well worth while. Incidentally it may be remarked that as a general rule, the void content of broken stone is higher than the void content of gravel. So, in addition to the fact that gravel is easier to work, because it ordinarily has a lower void content it is likely to be worth more to the contractor, though commonly it costs less.

There is no general rule which can be applied to matters of this sort with confidence that deductions based on this rule always will be correct, but as a sort of rule of thumb which will serve to suggest where more accurate calculations are likely to be of assistance, it is safe to assume that as between coarse aggregates, otherwise satisfactory, from 8 to about 11 cents should be added to the price per cubic yard which is asked for any coarse aggregate, except that one having the lowest void content, for each per cent that its void content is above the lowest offered. This will give its probable relative cost where arbitrary volumetric proportioning is used. Thus, for purposes of illustration, assume that three materials are available—a broken stone and two gravels, *A* and *B*. The following table illustrates the points just noted:

	Broken stone	Gravel *A*	Gravel *B*
Average void content, per cent	40	39	36
Price per cubic yard (f.o.b. material yard)	$1.75	$1.95	$1.85
Add for excess void content at 10 cents per 1 per cent of extra void content	0.40	0.30	0.00
Probable relative cost to contractor	2.35	2.25	1.85

Presumptions Should Be Checked by Laboratory.—A calculation of this sort merely indicates probabilities. Before the aggregate is purchased, the advice of a competent laboratory should be had. This will involve some expense, but the amount at stake quite generally is sufficient to warrant this expense. Variations in the average void content of the various coarse aggregates offered for a single job often will be as much as 5 per cent, and a variation of this amount could easily affect total production cost to the extent of from 30 to 40 cents a batch. As there are about 2,350 five-bag batches to the mile (standard Maricopa section), the effect on cost would then be from $700 to $1,000 a mile, a sum well worth considering. A good labora-

tory can make accurate determinations on yield and will do this work at a reasonable cost. There is, therefore, no need of running the risk of taking serious losses on account of the materials purchased, for a complete laboratory investigation on the relative value of available materials will cost much less than a mistake in the selection of the aggregates.

The Basis of Strength in Concrete.—The above remarks refer to conditions as they commonly are today. There is, however, plenty of evidence that the day of generalized volumetric proportioning is about over. Indeed the fact is unescapable that nothing is being gained by specifying a 1:2: 4 or a 1:2: 3½ mix, etc., in the hope that good concrete may be obtained when, as a matter of fact, what really is desired is concrete having a definite quality as, perhaps, a crushing strength of 3,500, 4,000 or perhaps 4,500 pounds per square inch. But, as the policy of specifying a desired quality replaces the present policy of specifying an arbitrary mix, the selection of materials is likely to become even more important than it is now. This matter will not be discussed here except to remark that, after maintaining the lowest water content from which a freely workable mix can be had and using a high quality cement, matters given entirely too little value under current specifications, the contractor is likely to find a low void content in the coarse aggregate the matter of most importance to him, for there is every reason to believe that the now almost universal practice of using a fixed amount of coarse aggregate without regard to its void content, with the result that there is a variable overage of mortar much of which often is in excess of any reasonable need, will be replaced by practices giving the contractor greater freedom in proportioning the mix. Under an open quality specification, economy would, in general, dictate the use of a coarse aggregate of low void content. This in turn would considerably reduce the mortar content and, with this reduction in mortar content, also would somewhat reduce the cement content. This is quite a logical result of the research work done in this field during the past few years. R. W. Crum, of the Iowa State Highway Department, has pretty definitely established the fact that in the prevailing diluted-mortar mixes used in paving work the strength of the mortar determines the strength of the concrete. To use mixes containing a lower percentage of mortar should, then, have no adverse effect on strength as long as the mortar content is adequate to fill the voids

in the coarse aggregate and provide reasonable workability. Indeed, if the water content is carefully held at a low ratio, these leaner mixes can rather easily be made to yield both good workability and a higher strength than now is common where standard mixes are used.

Proportioning.—The work of Prof. Duff A. Abrams, of the Portland Cement Association, also serves to emphasize the fact that adequate strength can be had from mixes of very low mortar content. The work of Professor Abrams goes much further than anything else ever attempted in this field and as a matter of fact clearly demonstrates that there are any number of combinations of coarse and fine aggregate which can be used in producing concrete of high strength. It is apparent, however, that, while a long range in proportions can be used, the economical proportions, that is, those offering both a desired strength and the largest yield from a given volume of materials, with proper workability, are those involving a somewhat larger stone content and a somewhat smaller sand content than are now generally used.

Proportioning by Weight.—Some approach to more rational proportioning is being made at the present time through the adoption of proportioning by weight. There is surprisingly little variation in the specific gravity of sand which commonly is about 2.65. Ordinary gravel has a similar specific gravity. The specific gravity of broken stone varies more but can be easily determined in a good laboratory and usually is pretty constant in a given quarry. As these materials are used on a paving job, they contain a little moisture. The moisture in sand will run from as low as 2 per cent or less to as high as 5 or 6 per cent, the latter percentages being found in freshly washed sand as delivered to the material yards or after rains. In general, the average moisture content of sand as used on a paving job is a little more than 3 per cent. Coarse aggregate seldom carries an average of more than 2 per cent of moisture, though when freshly washed and just after heavy rains a good deal more moisture than this may be found on it.

These facts can be and in fact are being used as the basis for proportioning aggregate by weight, a given weight of sand or of gravel or of broken stone being determined to equal 1 cubic foot of this material. If, as an illustration, the sand is found to weigh 108 pounds per cubic foot and the stone 102 pounds per cubic foot, a 1:2:4 mix would require 216 pounds of sand and 408

pounds of stone per bag of cement used. To these weights the allowance for moisture must, of course, be added. The weights for the sand and the coarse aggregate used in work of this kind should be those of the dry-rodded materials. In no case should the weight of material measured loose in the field be used. The purpose in using a weighed batch is correctly to express the specified proportions in the field. There is a wide difference between the weight of materials as determined in the laboratory and as determined from loose measurement in the field. The contractor always should insist on the use of laboratory weights.

A Weakness in the Weighing Method.—The weighing method has proved very satisfactory wherever it has been used and is definitely to be preferred to volumetric proportioning as now practiced. It must be remembered, however, that it contains this element of weakness, namely, that a constant weight, particularly of coarse aggregate, is not a constant volume. If the void content chances to be high, the volume of the coarse aggregate, as weighed, will also be high. It has already been noted that, under present practices in proportioning, there commonly is a considerable surplus of mortar. As long as this condition holds, the weighing of aggregate merely tends to standardize the size of the batch—the yield—but if the normal batch is none too well supplied with mortar, a condition which sometimes occurs when crushed stone is used, and if a few batches of material of unusually low void content are encountered, there may be an obvious deficiency in mortar. This will occasionally occur, too, when gravel is being used if, in stock piling, the coarser particles have been allowed to accumulate on the outside at the bottom of a large stock pile. An occasional batch deficient in mortar is of no particular consequence, as the overage in mortar from other batches will correct this, but if the trouble persists, it is difficult to handle at the mixer. As proper handling of the coarse aggregate at the material yard will avoid the trouble, it is not to be considered as an objection to proportioning aggregate by weight. Indeed, in spite of such matters as this, the method is an improvement over arbitrary volumetric proportioning and should be used by contractors wherever it is permitted, for it avoids variations in the size of the batch.

This method has not, as yet, been at all widely applied, so as to eliminate the large mortar surpluses that are a feature of present concrete paving work, but this is bound to come at no very distant

date, for specifications which have a broader economic justification than those now in force are certain to come into more general use. When such specifications come into vogue, the value of weighing equipment, particularly as applied to the measurement of the fine aggregate, and of a low void content in the coarse aggregate will be so great that profitable operation cannot be expected if they are overlooked.

CHAPTER IV

PREPARING THE SUBGRADE

Before the actual work of laying the pavement can begin, the subgrade must be brought to grade. The practices which govern the construction of a subgrade differ a good deal from place to place, and the general manner of letting this work has changed a good deal during the past 10 years. A few years ago it was customary to let this work and the work of paving at the same time and commonly to the same contractor. Indeed this is still done in a good many cases. There now appears to be an increasing tendency, however, to let grading work at one time and then, a year or more later, to let the work of laying the pavement. If the first practice is followed, the paving contractor may handle the grading himself or he may sublet it. If the second practice is followed, it is practically certain that grading and surfacing will be done by different contractors. In any event, whether the paving contractor does the work himself or sublets it, or whether it is handled as a separate contract, it is almost always performed as a separate operation by an organization distinct from the paving organization and somewhat in advance of paving.

The Cause of Irregular Subgrade.—The ordinary practice in designing subgrades is to allow for some settlement of the fills, but neither the rules governing this allowance nor the practices of engineers in applying these rules are well established; so the actual grade line to which the grading organization works in placing the fills may differ a good deal from the finished grade line to which the pavement must be laid. This variation is caused by increasing the height of fills for the purpose of offsetting the shrinkage which, it is assumed, will take place before the pavement is laid. But as the basic knowledge on which such allowances rest is very incomplete, and as the application of such knowledge as there is, by no means uniform, and the time interval elapsing between the completion of the grading and the placement of the surfacing are highly variable, it is the common experience of paving organizations that allowances for shrinkage

have been incorrect. As a result the subgrade almost always requires additional treatment before the fine finishing for the pavement can be undertaken. It may also be appropriately remarked that grading operations at best are conducted with no great accuracy. A subgrade finished to the nearest tenth of a foot would be considered an accurate piece of work, but the forms for a concrete pavement ought to be set to the nearest tenth of an inch; so the basic standards of accuracy differ widely.

Ordinary Conditions of the Subgrade.—These considerations effect the condition in which the subgrade exists when the paving organization begins operations and, together, account for the fact that it is the common experience of contractors that the subgrade will require considerable re-treatment before fine grading can be attempted. Moreover, because the general tendency is to make rather liberal allowance for shrinkage, subgrades tend to run high. A 6-inch excess in the height of fills is common, and the author has seen cases where the excess was over 18 inches for considerable distances, though cases as bad as this are rare. On the other hand, low areas, though not so common, are encountered rather frequently. The result is that the first operation incident to laying a pavement is, of necessity, regarding the subgrade.

Amount of Work Involved.—Moreover, this may be a serious element in the cost of paving. Subgrades now commonly run from 26 to 36 feet wide. If a 26-foot subgrade is running 6 inches high, the excess material amounts to almost ½ cubic yard per lineal foot, and if a 36-foot subgrade is running 6 inches high, the excess amounts to ¾ yard per lineal foot. This is at the rate of about 2,600 cubic yards to the mile in the first instance, and at the rate of about 3,900 cubic yards to the mile in the second, and while it seldom happens that averages of this order of importance continue uninterrupted for long distances, the accumulation of the yardage which is involved in reducing these high areas often reaches rather imposing figures before even a project of moderate length is completed.

Propriety of Modifying Grade Line.—The nature and amount of this grading work, whether it involves merely the reduction of high areas or includes, as well, bringing low areas up to grade with the necessary haul on the material moved from the high areas to the low areas, are not of as much concern to the contractor who is working where the interpretation of the prevailing specifi-

cations classes this as grading work and pays for it as such, as it is where this work is considered part of the regular paving work. If it is classed as grading work, the contractor can enter a unit price on it with reasonable assurance that no conditions will arise that will cause him any serious loss because of unexpectedly heavy work. But if this work is treated as part of the regular paving work, payment for it being included in the unit price for pavement in place, any unusual inaccuracy in the subgrade is almost certain to involve heavy expenditures for which no allowance has been made in the bid price. When faced with a situation of this sort, the contractor can reasonably ask for such an adjustment of the grade line as will reduce the amount of correction more nearly to normal. Commonly, as a matter of design, the selection of the grade line is governed more by personal preferences than by any established rules; so its minor modification under circumstances of this kind ordinarily offers no great difficulty and causes no reduction in the value of the finished structure. Such adjustments should, therefore, be encouraged by responsible engineers. Some engineers now make modifications of this kind readily enough, but more take the stand that, as the contractor is presumed to have known of such conditions as this before he entered his bid, a modification of this sort is an act of favoritism. This view overlooks the fact that competitive conditions set prices in paving work just as they do in other business enterprises and that the contractor's first business is to obtain the work, after which he must complete it for less than the bid price, if this is possible. He must, in short, bid the prevailing price to get the work, and as a result, unusual conditions of this sort are apt not to come to his attention until they are encountered on the job. Indeed it may be remarked that the tendency among contractors is to place so much confidence in the reliability of engineers that they assume that unusual conditions do not exist, which fact of itself is a perfectly valid reason that engineers should correct unusual conditions as far as it is possible to do so, whenever they do, in fact, obtain.

Grade Should Be Set Low.—In handling whatever grading work must be done before subsequent operations can be properly and expeditiously performed, the paving contractor must consider not only the immediate cost of this particular work but the effect of the methods and practices used here on subsequent

operations. As one illustration of this, it is now the general practice among engineers to set grade stakes for the control of grading operations at the elevation of the bottom of the pavement at the crown. The grade is, in theory at least, finished level across its width at this elevation. If this practice is followed, when the fine finishing of the grade is done, it is necessary to trench the rough grade to obtain a bed of the proper shape for the pavement and during this operation to remove a considerable amount of material which must be carried to the shoulders. For this reason, where prevailing specifications will permit of this practice, it is more economical to have the rough grade finished to a level far enough below the bottom of the pavement at the crown so that when the subgrade is cut out for the thickened edge and for setting the forms, the material so removed will be just sufficient to construct the required crown in the subgrade. For most of the current designs the difference in elevation involved is about 2 inches.

Objection to this treatment of subgrade operations is sometimes raised on the ground that, if applied to the initial placement of the grade, the material delivered is not sufficient to provide adequately for shoulder construction. This is admitted. But the fact should not be overlooked that the present practices require (1) the delivery and placement of material along the central area of the subgrade which later will go into the shoulders; (2) digging up this shoulder material and removing it to the shoulders where it is dumped with no particular attention to its ultimate use; and (3) digging up this material and redistributing it in its final and proper position in the shoulders. One of the functions of management in pavement construction is to eliminate useless work, and while this is a relatively minor matter, it is so apparent that handling shoulder material three times, as present practices commonly require, cannot be as economical as handling it once, that no extended argument on this point seems necessary in order to justify the statement that efficiency dictates the abandonment of prevailing practices in establishing the preliminary grade line for this work.

The Blade-tractor Combination.—There are a number of methods which may be applied in bringing a subgrade to the proper grade. The simplest and, on the whole, the cheapest way to reduce high areas is to cut them off and throw them aside with a short heavy-duty blade drawn by a 5-ton crawler-type tractor

(see Fig. 11). The various adaptations of the farm tractor are too light for this work. On the other hand, while the 10-ton crawler-type machine is often used, it is, on the whole, heavier than is needed, though this is not a very serious objection to it, for the larger machine has many other possible uses about a paving job. But, as noted above, the subgrade seldom runs consistently high; so the blade-and-tractor combination has not been altogether a success, for, in the nature of the case, it cannot move much material along the road. In some places enough material can be recovered from the shoulders and slopes to build up low areas, but a more promising arrangement is the substitu-

FIG. 11.—Subgrading with a blade grader. Note fresnos behind grader.

tion of a large-sized fresno or a tool of similar characteristics for the blade grader when material must be moved longitudinally in the correction of low grade.

Fresnos.—When a blade is used for the reduction of high areas, it must, in the nature of the case, begin at the edges and throw material out until the area where the pavement is to be placed is cleared, though if the amount involved is not too large, it is sometimes practical to begin farther in and pile the surplus along the shoulders. For this reason the blade-and-tractor outfit generally handles more material in correcting the grade ahead of the paving

than it is necessary to clear away at that time, for the objective is a correct subgrade for the pavement and this really requires a working area only about 2 feet wider than the pavement. This has led many contractors to continue to use fresnos on this work. A plow and two or three fresnos (see Fig. 12) can adjust the subgrade rapidly and economically, hauling longitudinally whenever necessary. When fresnos are well supervised, they can secure an accuracy of accomplishment that it is hard to surpass with any other type of equipment. They can also work effectively under almost any subgrade soil condition. With the advantage that where the grade must be lowered, the fresnos can do this without

FIG. 12.—Fresnos at work subgrading. Note common though incorrect method of taking off material through an opening in the forms.

moving material in the shoulder strips except as this is necessary in order to place the forms and with the added advantage that they can be used in cleaning up ditches and building shoulders, they have proved a generally satisfactory and an outstandingly reliable tool.

The Operation of the Fresnos.—Where fresnos are used, the forms should not be set until the subgrading has been completed. The time required in handling a load of earth by fresno is the sum of an interval of time consumed in loading, turning, and dumping—operations which must be performed on every load moved—and an interval of time required for hauling the load to

the dump and returning for the next load. While the first of these intervals is pretty constant, as the same operations have to be performed in about the same way with each load handled, the second varies directly with the distance the material is moved and amounts to about 1 minute for each 100 feet the load is hauled. If no forms are in place, the fresnos can reach the shoulders at almost any point; so the haul distance can be kept low, a round trip being easily made in from 1 to 1¼ minutes. But if the forms are in place, the only approach to the shoulders

FIG. 13.—The result of the incorrect method shown above. Note unequal distribution of each along shoulders.

is through openings in the forms (see Figs. 12 and 13), which in practice are made about 100 feet apart, the general system of operation being to drive out through one opening and back through another. This lengthens the haul distance to 100 feet or more, and extends the round-trip time so that it tends to become as much as 2 minutes or more, with the result that the amount of earth moved by each fresno during the course of a day's work is correspondingly reduced. As no advantage is to be had by placing the forms before the grade is adjusted, efficiency dictates that the practice be avoided.

Other Methods.—There are a number of other methods which are used in correcting subgrade, but none of them lend themselves to economy and dispatch. Slip scrapers are still used in some places, though they are neither economical nor efficient. Even hand labor is employed in places! But methods of this sort merely invite financial trouble, as they are relatively slow as well as expensive.

Crowning the Subgrade.—Reference has been made to the fact that it is commonly assumed that the rough grade will be finished level across its width. While this is the ordinary manner in which it is laid down, the paving contractor should, in his own interest, correct this condition as rapidly as possible after work starts, developing and maintaining a light crown on all of the uncovered subgrade over which he must work. About a 3-inch crown will be satisfactory under most conditions. If such a crown is maintained, the run-off during heavy rains will be relatively rapid, and the loss of time on account of wet subgrade correspondingly reduced. If there is any indication of rain, particular care should be exercised to provide free and ample run-off ditches wherever work on the subgrade has left it lower than the shoulders and wherever forms are in place. Such precautions cost little, but during a long working season they save a good deal of working time.

CHAPTER V

FINE GRADING AND FORM SETTING

In the sequence of operations which must be performed in the construction of a concrete road, form setting and fine grading naturally follow the regrading of the subgrade. As a matter of fact these operations often are merged, but to do so has the disadvantage of so concentrating this work on the subgrade and particularly the machinery used in performing it that interference with the delivery of material is apt to result. It is, therefore, a safe practice to keep the work of correcting the subgrade about a normal day's run ahead of the form setting and fine grading, which, as a matter of working policy, should be kept about a day's run ahead of the mixer. No advantage is likely to accrue from keeping these operations farther in advance of mixing than this except on jobs where delivery is by industrial railway, for there are too many factors, such as traffic, weather, etc., which tend to destroy the value of any work done much farther in advance of paving, and certainly they should not be conducted much closer to the mixer, both because the equipment used in performing them tends to interfere with handling the trucks and because a reasonable working margin should be provided against breakdowns or other conditions that may temporarily interrupt the work. Then, too, in all of its aspects paving work is properly to be viewed as a series of operations each performed at a rate which yields production in harmony with production at other points. This aspect of paving work is quite as applicable to subgrading, to form setting, and to fine grading as it is to any other part of the work. In short, both the safety of the work itself and the job policy of a uniform rate of production in all departments tend to control the position of this work with reference to the mixer.

Importance of Accuracy.—Form setting and fine grading are among the more important of the operations performed in connection with paving work. Form setting is important because the subsequent finish to a large extent depends on the accuracy with

which the forms are set. Subgrading is important, because carelessness here can easily endanger the structural adequacy of the pavement and may adversely affect the quantity of concrete which must be used in building the pavement and with this, of course, the cost of the finished work.

Order of Work.—Assuming that the grade has been corrected, as described in the preceding chapter, the first operation incident to fine grading and form setting is to cut out for the thickened edge, using a short heavy-duty blade and a 5-ton crawler-type tractor to perform this operation. With this same operation most of the material which must be removed in order to set the forms should also be taken out. Following this operation, the

FIG. 14.—Setting the forms. Note effect of trucks on subgrade in foreground.

seat for the forms should be trimmed out, the ground being cut about ¼ inch low and filled back to slightly above grade with loose earth. One man with a mattock can handle this work unless the subgrade is composed of unusually difficult material.

Following the trimmer, two men set the forms (see Fig. 14) in approximate position, drive the holding pins, and bring the forms to preliminary line and grade. It is the general practice to guide these operations by means of a string line. Form stakes are set in a number of ways, but the practice best suited to the contractor's needs is to set these stakes, which give the exact grade for the tops of the forms, about 50 feet apart on tangents, 20 to 25 feet on curves, and 1½ or 2 feet outside of the forms.

These stakes are set on both sides of the road. To guide the trimmers as well as to govern the form setters, the workmen drive steel pins, commonly surplus form pins, at the proper offset distance from the engineer's stakes and string a stout cord between these stakes to govern line and grade, grade being transferred by means of an ordinary carpenter's level. This method naturally falls short of absolute accuracy, but if carefully done, the errors are no greater than in other parts of the work.

Avoiding Form Settlement.—Some makes of forms are so constructed that, if the subgrade is reasonably dry, the pins will carry the total weight of the forms and of any machine which must operate over them. To accomplish this, the wedges must be tight, but where the subgrade is at all plastic, no dependence should be placed in the pins, for under such a condition the pins do not have enough frictional bearing on the soil to develop a carrying capacity adequate to support the weight either of the subgrader or of the finisher, and form settlement is likely to result. Extended measurements of form settlement show that the box type of forms settles less than the L-shaped forms. This is evidently due to the fact that with most designs of the L-shaped forms the total weight of the finishing machine is transferred to the base through the web, with the result that the inside edge of the base is overloaded before the base as a whole comes into bearing. There are, of course, various devices used to counteract this tendency, but none of them appear to be fully effective under everyday field conditions.

No matter what style of forms is used, it is good practice to bring each section of the forms to grade by moving it about a little on the loose dirt which should be left by the trimmer, as a brick is moved about by the mason to give it a good bed and bring it to proper level, before the pins and the wedges are driven, rather than to dig deeper, as is some-times done, and adjust the forms to line and grade by wedging them up on the pins, or setting them on small piles of dirt, after which the space under them is backfilled and tamped. Of course, this latter practice is objectionable in principle because of the relatively large amount of unnecessary work which it throws onto the trimmer who, if this system prevails, must dig at least ½ inch below the forms if good backfilling and tamping are to be done and because the backfilling and tamping require the time of from

one to two extra men, from whose activities there really is no return, for when well done, this method yields results no better than the one first outlined, whereas, if, through any carelessness, the tamping is poorly done, the settlement of the forms may become a really serious factor in reducing both the smoothness and the thickness of the finished pavement.

Scarifying and Crowning the Subgrade.—After the forms are set, aligned, and wedged up, the subgrade between them should be thoroughly scarified to a depth of from 2 to 3 inches. This operation reduces the subgrade to a reasonably uniform compaction. In particular it avoids the alternate hard spots and soft areas which are a common condition after a subgrade has been subjected to heavy rolling. It is a frequent occurrence that under such rolling some areas become so hard that they will carry the weight of the roller without further give, while near-by areas never come to a high state of compaction because the weight of the roller is carried on the more compact areas, a condition particularly likely to prevail if in reshaping a subgrade fairly solid areas are cut off to fill low spots. This hardly offers a satisfactory bed on which to rest a valuable pavement.

There are, of course, places where scarifying the subgrade would not be permitted. It is not necessary here to go into the theories that appear to govern the specifications which define the preparation of the subgrade, but it may perhaps be remarked that there are two pretty well-defined opinions in regard to the proper condition of the subgrade when a pavement is placed on it. One of these is that it should be as solid as possible. The other is that it should be moderately yielding. Not enough is known about either the internal stresses in a concrete pavement or the behavior of subgrades to justify any very dogmatic opinion as to which type of subgrade gives the better results, but it appears that the insistence on heavy rolling of the subgrade which was practically universal a few years ago in gradually giving way to methods yielding a more moderate degree of compaction. This is quite reasonable, for even if it were admitted that a high degree of compaction in the subgrade is desirable, it could by no means be shown that a high degree of compaction artificially produced can be permanently maintained. Frost action, boring beetles, worms, etc., all tend to destroy such a condition and so to render the expense of producing it of more or less doubtful value.

Where heavy rolling is required, however, it must be done, but even if such rolling is required, it may still be more desirable to use a scarifier. This will depend somewhat on the conditions prevailing. If the ground is reasonably moist, it can be scarified to advantage (see Fig. 15), bladed to shape, corrected by the subgrader, and rerolled, a good subgrade being more easily produced in this way than by hand trimming and rolling. If on the other hand the subgrade is dry and no ample water supply is available for wetting it, a treatment such as this is likely to meet the objection of inspectors on the ground that recompaction is not adequate.

FIG. 15.—The scarifier and the tractor.

The Subgrader.—Where heavy rolling is not required, the subgrade, after having been scarified, should be bladed to approximately the correct crown. It is well to blade the crown a little high, as the subgrader will correct this defect more easily than it will correct low crown. Following the development of the crown, the subgrader (see Fig. 16) should be pulled. For this work the blades should be set from ¼ to ½ inch high, depending on the amount which light rolling has been found to compact the loosened subgrade material. The subgrader should make two or three round trips over each area to insure accurate work. Pulling it once will not accomplish the desired result. Indeed, much of the inaccuracy in the subgrade which develops at the mixer is

traceable to an insufficient use of this tool. As the subgrader often leaves the subgrade in apparently good condition the first time it is pulled, it is quite natural that the value of a second or third passage of the machine should escape notice. It is a fact, however, that the third trip and sometimes even a fourth will yield enough additional correction of the subgrade more than to justify itself.

The Reason for Careful Work.—Too much care can hardly be taken with this work, particularly with the careful elimination of all low areas. At this point in the development of the subgrade, low areas can be filled without raising any objection, and this

FIG. 16.—The subgrader.

should be most scrupulously looked after, for it will be apparent that if all of the subgrade is brought to exact grade at this time, the only injury to it that is at all likely to occur is a little rutting as the result of the delivery of material. Sometimes this is serious, but in ordinarily good weather it is not much of a problem. Moreover, the serious overruns in material of which contractors complain are not due to rutting but to the existence of large areas where the subgrade has never been brought up to grade. Speaking in a general way, subgrade that is $\frac{1}{3}$ inch low causes a 5 per cent overrun in quantities. The reason for using a good deal of care that all of the subgrade shall be up to grade is therefore apparent. The cuttings which are piled up behind the

subgrader (see Fig. 17) can be removed by hand or by a fresno, depending entirely on how accurately the grade was previously corrected.

Rolling and Final Shaping.—After the subgrade has been shaped by the subgrader, it should be lightly rolled by a light (1½- to 3-ton) roller (see Fig. 18). The forms should then be carefully checked, after which the subgrader should be pulled again, particular care being taken to bring up all low areas. The

FIG. 17.—Careless work on the grade leaves too much material to be handled by the subgrader.

machine will take care of the high spots! Before making this last trip, the blades should be dropped to cut not over ⅛ inch high. It is better to keep the subgrade a little high than to let it run a little low, for if the subgrade is a little low, it is hard to detect this and harder still to devise any method of correcting it at the mixer which is certain to meet the approval of inspectors. The planer will reduce high areas back of the mixer if these are not over ⅛ inch above proper grade.

Effect of Low Subgrade.—It is, of course, essential that the contractor furnish a pavement as thick as the plans require. On the other hand, there is no obvious reason for presuming

that it is less essential that means be devised by which this can be done without injury to the contractor. If the contractor is required to give at least the full thickness of pavement at all times but is not allowed to build up low subgrade except by the use of methods as expensive as filling the low areas with concrete, the result is a constant overrun in quantities, for concrete will be used if other permissible methods of filling low areas are equally expensive. The matter of overruns will not be discussed here further than to remark that their actual cost is much higher than seems generally to be supposed. Indeed, a constant 5 per

FIG. 18.—The light roller at work on the subgrade.

cent overrun may easily cost the contractor from $125 to $200 a day. This is a figure quite comparable with his daily outlay for labor for the whole job, which is mentioned merely for the purpose of calling attention to the importance of overruns in terms that will be readily understood.

Thin Pavement.—The matter of thin spots in the finished pavement is receiving more careful attention all the time. Under the prevailing practice in design, concrete pavements are commonly thicker at the edges than at the crown. It would be impossible for anyone to say just why the particular dimensions which are used have been selected, for the plain fact of the matter is that concrete paving design is today almost wholly empirical. Design

really rests on the fact that experience has in a very general way shown that pavements of about a certain thickness will, under normal conditions, carry ordinary commercial loads. But as cost has, for years, been a controlling factor in highway design, it has been impossible for highway engineers to introduce the same factors of safety in pavement construction which are customary in other engineering fields. There is, in short, not much, if any, factor of safety in modern pavements as their too occasional destruction under traffic—a result almost unknown in bridge work, for instance—clearly establishes. But because considerations of cost have prevented the use of larger factors of safety in this field and indeed have even prevented the general use of adequate working tolerances, there is an increasing demand that more care be taken to avoid the loss of any of the strength implied by the design. The resulting prospect that the delivery of pavement which is at no point thinner than the design contemplates will be required presents a serious problem. Every one who is at all familiar with the conditions surrounding manufacturing knows that exact standards are seldom applied. It would, as an illustration, be possible to cut lumber to a variation in thickness as low as $\frac{1}{100}$ inch, but to do so would increase the cost of the lumber far beyond any value likely to accrue from so doing. Bricks probably could be made which would vary in length or width or thickness less than $\frac{1}{100}$ inch, but to insist that they be made as nearly alike as this would considerably increase their cost. Such illustrations could be multiplied indefinitely but would only serve to add greater emphasis to the fact that in manufacturing work of any kind—and paving is in all of its aspects a manufacturing enterprise—every increase in accuracy adds to the cost, and if the pressure for accuracy is great enough, the cost of securing the desired accuracy can easily rise to a point where it is out of all proportion to any value thus created.

The point it is desired to emphasize in this discussion is that, in the nature of the case, it is utterly impossible at any reasonable cost to cut the subgrade so accurately, to set the forms so true to line, and to hold them so firmly in place—to say nothing of the effect of the finishing operations on the surface of the pavement, of the use of excess water, etc., which are matters that will be discussed later—that, if a 6-inch thickness is attempted, it will always be obtained. Indeed, even after taking all of the care

which ordinarily can be exercised in the conduct of a concrete paving job, labor conditions, equipment, and general field conditions being considered, no contractor can reasonably be expected always to work within a variation of less than ½ inch from the thickness dimensions established by the plans. It is, of course, obvious that any one of the operations affecting the accuracy of the final cross-section of the pavement can be done more accurately than this, but it must be remembered that inaccuracy may be cumulative as well as compensating; that is, a low spot in the surface, to give an illustration at random, may come where the

FIG. 19.—The finished subgrade.

forms have settled or where they run high. The first condition adds the two errors, making the pavement thin by the amount of their sum, while in the second case, assuming that the inaccuracy in the surface and in the forms is equal, the pavement is of proper thickness in spite of the inaccurate work. In practice, it has been found to be impossible to handle subgrading operations, to say nothing of form settlement, so accurately that the subgrade will always be within less than ¼ inch of correct. Errors on the surface often exceed ¼ inch. For this reason, whatever minimum thickness at the crown or at any other point in the cross-section is desired, the thickness called for on the plans

should be at least ½ inch greater than the minimum which will be accepted on the basis of random cores.

Proper Allowance for Form Settlement.—In view of all of the conditions which adversely affect the accuracy with which concrete pavement can be laid, it is to be hoped that, as this matter is more generally understood by engineers, the policy in dealing with it will be so modified that the thickness called for will be an average thickness rather than a minimum thickness and that penalties will be imposed only when there are deficiencies in thickness which exceed some reasonable tolerance limit, as for instance, ½ inch, or possibly as much as 1 inch. But until this policy has general acceptance, the production manager should give most exacting attention to all of the details of construction which affect

FIG. 20.—Checking form settlement. Note form stake under level at left. If forms are to be checked these must be carefully preserved.

the thickness of the finished slab, and among these few are of more importance than rigidly exact and solid form setting and most careful preparation of the subgrade.

The problem of the production manager is to find and rigidly to follow a course of action that will avoid the penalities which are being imposed where pavement is thin. No degree of accuracy reasonably attainable will do this. On the other hand, the use of extra concrete costs an enormous amount of money, not far from $200 per mile for each 1 per cent of overrun. Probably the safest course to follow is to set the forms high by just a little more than the amount of the ordinary settlement of the forms, generally about 3/16 inch if L-shaped forms are used, and by accurate work at other points to reduce the variation in thickness as much as

possible. It may be observed here that extended examination of the behavior of forms leads to the observation that form settlement is more prevalent than commonly is supposed, particularly during the spring months. Serious settlement of the forms may take place in wet clay and gumbo soils even into the late summer months. It is so easy to check the forms (see Fig. 20) just after the finishing machine has passed over them, a carpenter's level being sufficiently accurate for this purpose, that a contractor can, if he will, catch up and correct unusual form settlement while the concrete is still green. Even in good weather and with good soil conditions, forms generally settle $\frac{2}{16}$ or $\frac{3}{16}$ inch. Setting the forms $\frac{3}{16}$ inch high counterbalances this tendency. But when the settlement exceeds $\frac{3}{8}$ inch, the forms should be picked up by jacks, refilled, and retamped.

CHAPTER VI

HANDLING THE AGGREGATE AND THE CEMENT

The material-handling problem on a concrete paving job, if considered in its entirety, would cover not only handling the cement, sand, and coarse aggregate but delivering the water, reinforcing steel, parting strip, and any other materials which enter into the work. However as the volume of such items as reinforcing steel and parting strip is relatively small, and as the problems involved in dealing with the water supply are wholly distinct from those involved in handling aggregate and cement, only these latter will be treated in this chapter. It may also be remarked that while only a few years ago it was rather a common practice among contractors to develop their own supplies both of coarse and of fine aggregate, a practice still followed to some extent, by far the larger part of all material for concrete paving work is now purchased from some established producer whose facilities are such as to encourage the belief that he can make regular deliveries and whose output has been so thoroughly tested that it may reasonably be presumed that the quality of any material furnished will be satisfactory. Purchasing materials is not one of the duties of the production manager, nor is it one of his duties to look after the non-arrival of materials, though it is, of course, one of his duties to keep the office posted as to the rate at which materials are needed and are being received. The work of the production manager, then, really begins with the arrival of the materials at the material-yard siding, for it should be remarked that rail delivery of the materials is today almost universal.

Rate of Delivery Governed by Rate of Use.—The modern conception of any manufacturing enterprise which involves handling a large volume of material—the production of concrete pavement is in this respect typically a manufacturing enterprise—is to govern the rate at which raw materials are delivered by the rate at which the finished product is being moved. This enables the manufacturer to move raw materials from the tracks direct to the point at which they are to be first treated, and not only

relieves him of a large investment in stored materials but also of the necessity of having a large storage space. Of course, this practice also cuts down handling costs, for commonly it costs as much or more to move materials from storage as it does from the cars to storage or from the cars to the point at which they first enter the manufacturing process; so, in effect, handling costs are only about half as great where materials are moved from the point of receipt to the point of first process as where they are passed through storage.

Factors Affecting Dependability of Delivery.—A system of this sort depends for its success, first, on the reliability of the material producers from whom supplies are purchased, and second, on the dependability of rail delivery. Moreover, it is important to bear in mind that, as a low cost is dependent on a high rate of production, no risk can reasonably be run as to the dependability of delivery, for any failure of the material supply is destructive both of organization and of output. If times are good and the volume of business is large, there is a tendency among material producers to book orders in excess of their output capacity. Wherever this happens, some of the jobs to which material has been sold are certain to face slow delivery. Occasionally all who are purchasing from an oversold producer will find delivery short, but it appears to be a far more common experience that the contractors who are paying the best price get full delivery, while those who are paying less get what is left. The problem which a contractor faces in dealing with oversold producers is a serious one. His production is at stake. Yet it is not customary to demand of material producers the same sort of guaranty on the delivery of material that is required of the contractor on the delivery of the finished pavement. Indeed, materials are commonly purchased on open order. A price is asked, the producer quotes, and the buyer accepts, naming a round quantity of the material desired. No formal contract is drawn, the quotation of a price with such terms as may be named and the order placed at this price being all the existing evidence of an agreement between buyer and seller. This lack of formality seems to be at the bottom of the generally irresponsible attitude of both buyer and seller toward these transactions. Contractors often cancel outstanding orders without the slightest legal justification for so doing and, as a result, producers feel justified in taking more orders than they can fill. On the other hand, because producers

so often take more orders than they can fill, contractors feel quite entirely justified in duplicating orders, hoping by this practice to obtain enough material to maintain production.

Formal Contracts Desirable.—The proper and from every standpoint the honorable as well as the safe way to handle the material problem is to enter into formal agreement as to price, quality, rate of delivery, etc. covering these matters in a carefully prepared, mutually acceptable written contract. Such an agreement entered into between a reliable contractor and a reliable producer would avoid many of the difficulties that are now the common experience of contractors who desire to maintain a high rate of production, and while some responsibilities that now are often avoided would have to be assumed, these would not offset the advantage to be had from the greater certainty of a uniform rate of delivery which a written contract would tend to bring about.

Dependability of Rail Delivery.—As to the second prerequisite of success, if the practice of governing the rate of material delivery by the rate at which pavement is being laid is to be followed—a certain rail delivery—little need be said. There are few operations in this country today which are conducted with the efficiency that prevails in handling freight by rail. Railroad companies are adequately equipped to handle their business and are handling it expeditiously. The time that is likely to be lost through any failure here is too small to be of serious consequence.

Dependability of Cement Supply.—It may also be well to remark that the delivery of cement commonly causes a minimum of trouble. Conditions surrounding the cement industry are such that the producers of cement, as a matter of business practice, do not oversell their productive capacity. The acceptance of an order by a cement manufacturer is, therefore, practically a guaranty of delivery. It is well to note, however, that when business is brisk, a cement mill may be sold so close to total productive capacity that it cannot honor a change in the rate of delivery which involves a sharp increase in the amount to be furnished each week. For this reason, when the cement mills are running close to capacity, the rate of delivery which is desired should be predetermined with considerable accuracy.

The Basic Reason for Storage.—But while, by taking proper care in selecting the producers from whom materials are to be secured, by covering the supply by contracts, etc., a highly

dependable delivery at the material yard may be secured, at the same time, accidents are unavoidable. Some of these will affect the delivery of materials, and some will affect the rate of their use. For this reason, it is sound policy to provide some storage. This storage is to be viewed as a balancing reservoir is viewed in a water supply system. The pumps keep running. When use exceeds pumpage, the surplus comes from the reservoir. When pumpage exceeds use, the surplus goes to the reservoir. This is exactly the function of the storage piles on a paving job as it is properly conducted today. If the mixer is working a little faster than today's rail deliveries, storage provides the difference. If today's rail deliveries somewhat exceed the demand at the mixer, storage absorbs the difference. On a smooth-running job, upwards of 90 per cent of the materials may go from the cars direct to the mixer. Even with only fair operation, 75 per cent of the materials should reach the mixer without passing through storage.

Factors Affecting the Selection of Yard Equipment.—The conception of the material-handling problem as one involving, first, the establishment of a proper rate of delivery to the yard, second, the most expeditious movement of material through the yard, and, finally, proper facilities for taking care of any divergence between the rate of use and the rate of delivery necessarily dictates the style of yard equipment. It must have ample capacity. It must be economical in its operation and dependable. It must be able to handle the storage problem.

A five-bag paver can mix 48 batches of concrete an hour under a specification requiring that the mix be held in the drum 1 minute. If a 1:2:4 mix is being used, this is 10 cubic feet of sand and 20 cubic feet of gravel, a total of 30 cubic feet. If a 1:2:3½ mix is used, the total is 2½ cubic feet less. If a six-bag batch is used, the aggregate for a 1:2:4 mix measures 36 cubic feet. If production is at the full obtainable rate under specifications requiring a 1-minute mix, a batch must be supplied every 1¼ minutes; so the maximum demand on the unloading equipment is 1⅙ cubic yards every 1¼ minutes, or 53 cubic yards per hour where a five-bag mixer is in use, and 1⅓ cubic yards every 1¼ minutes, or 63 cubic yards per hour where a six-bag mixer is used. Production at these rates is seldom attained even for short periods, and even more seldom maintained for long periods, but jobs are on record where the sustained production over consider-

able periods has been at a rate within 5 per cent of that here given as full production. There are, then, well-authenticated records of sustained demands on the unloading equipment amounting to 50 cubic yards an hour where five-bag pavers have been in use, and there seems to be every reason for presuming that with the new six-bag pavers the sustained rate of demand may reach 60 cubic yards an hour. These rates are set by the demand at the mixer. They are, however, the highest rates which, in practice, need to be met. Occasionally, material will be brought in for short periods at a higher rate than this, but it is better to pay for a little overtime in unloading this, if that becomes necessary, than to provide unloading equipment which is heavier and more expensive than really is needed to serve the mixer.

Reciprocal Demurrage.—As a matter of fact the necessity of passing material to storage when more is brought in than can, at the moment, be used, would, in large part, be obviated if contractors would avail themselves of the privilege of reciprocal demurrage. Under this privilege savings in the allowed time for unloading cars can be used to offset delays in unloading. There are some formalities connected with securing this privilege, and disposing of these takes a little time, but the privilege is well worth securing, both because it will enable a contractor to avoid demurrage charges and because it will enable him to adjust a good many irregularities in delivery without passing the materials through the stock piles. Application for the reciprocal demurrage privilege should be made through the division freight agent of the railroad over which delivery will be made.

The Crane.—The gas or oil crawler-type crane equipped with a ¾-yard clamshell bucket (Fig. 21) has come into general use as the standard unloading equipment. In the hands of a good operator it can move a bucket of sand or coarse aggregate from the car to the hopper every 30 seconds. Moving material from the stock piles to the hopper takes a little less time than is required for moving it from the cars to the hopper.

Output Capacity.—The bucket readily picks up a full load—¾ cubic yard—when working in a full car of sand or from the sand stock pile and nearly a full load when working from a full car of gravel or stone or from stock piles of these materials. But as a car is emptied, a point is reached where it becomes impossible to pick up a full load. For that reason the average load per bucket when emptying cars of sand is about $\frac{6}{10}$ cubic yard, but

when emptying cars of gravel or stone it is seldom over $\frac{5}{10}$ cubic yard (Fig. 22). The maximum rate at which an ordinary $\frac{3}{4}$-yard crane in the hands of an ordinarily good operator will

FIG. 21.—The crane at work.

FIG. 22.—Clamshell unloading gravel, not fully loaded. When working out of a car the bucket seldom picks up a full load.

unload materials is therefore about 72 cubic yards an hour for sand and about 60 cubic yards an hour for coarse aggregate, or at the rate of about 65 cubic yards of material in the proportions commonly used in paving work.

From this it will be apparent that while the standard ¾-yard crane is large enough to handle the materials for a five-bag mixer, even when this is operated at a very high rate of efficiency, and can handle the material for a six-bag paver under similar conditions, the margin in the latter case is so small that it would appear to be advisable to consider the use of a 1-cubic yard bucket where a high rate of output is to be attempted with a six-bag paver; for it is desirable that equipment of this sort have a somewhat higher productive capacity than the key producer, as this will enable it better to catch up short delays which might otherwise affect production at the mixer. In unloading from cars to storage, the rate at which the bucket is loaded and emptied is a little higher than when the hopper is being filled, but the possible daily output is less because of time ordinarily lost in shifting cars. When working into the hopper, there is no necessarily idle time, for when the cars are being shifted, the crane can work from the stock piles.

The Use of Unloading Pits.—Where it is easy to obtain an ample supply of bottom-dump cars, a little higher output can be secured from the crane if pits are dug at the side of the track and far enough under it so that material can be discharged into these pits. Where this system is used, the crane loads from these pits, which tends somewhat to increase the speed of operation because the caution required in handling the bucket in a car is not required here. Also, as the pit is seldom worked clear to the bottom, a better average load is had. The system cannot be recommended where a five-bag batch is used, as the crane has ample capacity when working from the cars; so preparing the pits is an extra and an unnecessary expense, but where a six-bag or larger batch is being used, the method is worthy of consideration.

Advantages of the Gas Crawler-type Crane.—The gas- or oil-burning crawler type of crane is the most versatile equipment that has ever been used on this work. It is, of course, an expensive piece of equipment but it can be operated by one man without auxiliary equipment of any sort; so the labor cost of operating it is low. Fuel and oil costs compare favorably with similar costs on steam-driven equipment, and depreciation, while apparently a little higher, is not enough higher to offset the cost of firing the steam-driven equipment, to say nothing of the cost of delivering water and fuel where steam-driven equipment is used. Water delivery quite commonly takes the full time of a man and

team, and often the machine is so designed that it has to be shut down while the water is taken on. All of these things tend to make the cost of operating steam equipment higher than the cost of operating good gas- or oil-burning equipment.

The crawler type of crane has also proved to be a dependable piece of equipment, and as the boom is relatively short, the machine is relatively fast. The customary set-up is (Fig. 23) between the track and the hoppers, storage being on either side, though in close quarters storage may be between the hoppers and the track in which case the crane will work from the top of the coarse-aggregate storage pile.

Some of the Effects of Large Storage.—A crane of this type is a very mobile piece of equipment and so can store material almost without limit if space is available. The boom is relatively short, but the whole machine can be shifted from place to place along the storage area with great ease; so in the event large storage must be accumulated, this can be done without the slightest difficulty. It should, however, be appreciated that storage always is, in principle, an expense, for it involves rehandling materials. From the practical standpoint, however, this is not quite always true. Thus, for instance, if the total amount of work which must be done in loading the hopper and in passing a little material to storage or taking a little from storage can be done without using extra working hours, the actual increase in operating cost is negligible. It is only when the equipment must work more hours per month because of handling material to or from storage than other plant units work, that storage develops increased cost. The common condition as a contractor faces it, however, is that the crane must stock pile the material which is received when the mixer is shut down and take material from these piles when delivery to the yard is, for some reason, held up. The result is that the crane does work more hours than the mixer, which, of course, means that, on an ordinary project, passing material to storage does cost something, and so as little of it as possible should be done. Of course, any such practice as receiving materials during the winter unavoidably causes storage costs, for if this is done, the crane spends all of its time for a considerable period passing materials from storage to the hoppers. Moreover, when large amounts of materials are stored, the piles become so long (Fig. 23) that the material may have to be shifted to bring it within reach of the hopper. This may add a third handling

and, if production is high, treble the handling cost, as it may be necessary to do this shifting as overtime work.

Another objection to large storage is the heavy loss of material that it necessarily involves. The amount of material lost depends on the nature of the ground on which the storage piles rest and on the area of these piles. It is perfectly obvious that under all ordinary circumstances the smaller the amount of material passed to storage, the smaller the storage piles will be and so, naturally, the smaller the loss of material from this cause. As an objection to extensive stock piling, handling costs and material losses

FIG. 23.—A typical material yard.

are in addition to financing costs, interest on the capital which is invested in stored materials, etc. Often from the standpoint of the contractor, the most serious aspect of stock piling is the effect which it has on his working capital. This is not, however, one of the problems of the production manager and so need not be discussed here. It is mentioned because, though under normal conditions the various disadvantages of extensive stock piling which have been noted will appear serious enough to make general advance stock piling inadvisable, the financial objections to such a course are apt to be even more serious.

The Batch-measuring Hopper.—Each charge sent out to the mixer must be measured in some way. Commonly this is done

volumetrically, but it may preferably be done by weight. In either case the material must be placed in a large hopper and, by gravity, passed to the measuring device. Speed and accuracy are the essential qualifications of a good measuring device. Volumetric measuring devices can be had which will handle a batch in about 15 seconds. Weighing devices take about 45 seconds. In either case, the time involved is well within the mixer cycle—75 seconds, or 1¼ minutes. Moreover, if the trucks are kept properly spaced, either filling the volumetric measuring device or weighing the batch can be done between the departure of one truck and the arrival of the next; so these devices do not, of necessity, cause single-batch trucks any real delay, and two-batch trucks are delayed only briefly.

FIG. 24.—Modern steel hoppers set up to permit through driving, no backing required. Note volumetric measuring boxes below main hoppers.

The modern hopper (Fig. 24) is a well-built steel bin, mounted on four steel posts which are long enough to give ample clearance for the trucks. For security against accident the hopper should be set on concrete or other substantial pedestals, and as a matter of practice these should be placed long enough in advance of a move so that they will not interfere with its being completed promptly. Serious accidents have been caused by the failure to erect hoppers on proper footings.

Some of the hoppers are designed so that they can be set up and taken down very rapidly. This is a highly desirable feature, as many paving jobs are so long that a number of set-ups must be used. When a shift must be made from one material yard to another, time is an essential element, for a paving crew will not remain long on a job without work, to say nothing of the desir-

ability of avoiding any practice that interferes with the prompt completion of the job. It is not, of course, desirable to sacrifice stability and strength to ease of erection. Rather the thought is that no matter what the stability and strength, a hopper should not be considered adequate unless ease of erection has been considered in its design and in its construction. The size of the parts is of comparatively little importance, as the crane and the trucks can handle pieces of any reasonable size.

The Disadvantages of Homemade Bins.—Homemade wooden bins (Fig. 25) should be considered a thing of the past. They are

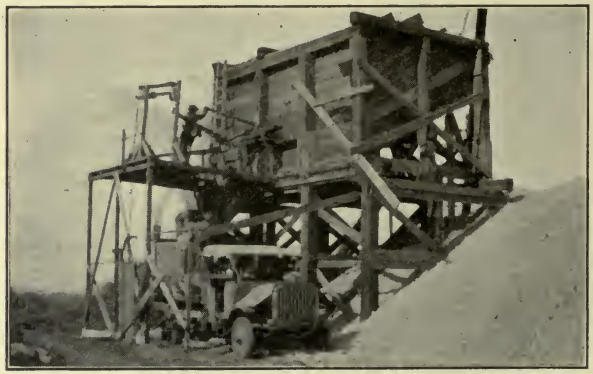


FIG. 25.—A typical, slow, inefficient, homemade loading bin.

seldom economical even in the matter of direct cost, and when the effect of their generally unsatisfactory operation on truck time is considered, they often prove astonishingly expensive. The homemade bin which is so built that it takes 1 minute to load the gravel and requires the use of another ½ minute to enable the truck to get into position under it requires the use of an extra single-batch truck wherever the rate of production is high. This will cost about $10 a day, a sum sufficient to pay for a good bin in rather a short time! Yet homemade hoppers that cause losses of truck time which are as small as this appear to be the exception rather than the rule.

The Position of the Hoppers.—The position of the hoppers in the yard is an important matter. Indeed, as time is an essential element in obtaining high production, it must be saved at every point on the job. For that reason it is an invariable rule that the yard layout should be such that no backing is required. Backing takes both time and space. Moreover, it is hard on the trucks.

It is better to spend a little time on planning a yard layout than to waste a good deal of truck time getting equipment through a poorly designed yard. The hopper should always stand far enough forward of the material piles to permit the trucks to drive through. To accomplish this, it may be necessary to hold back the stock piles in some fashion, but this is far less expensive than requiring the trucks to back under the bin from the front for the rather simple reason that it takes less time and offers no excuse for other delays.

Tunnels.—If industrial railway is used, the hopper at the material yard is sometimes replaced by a tunnel, materials being piled over the tunnel and fed by gravity to measured compartments in the batch boxes, of which, if standard five- or six-batch mixers are in use, each car carries two. The tunnel method of loading cars has an appearance of simplicity and speed in operation but does not confirm this appearance in actual operation. Time studies indicate that getting into the tunnel and out of it takes more time than is expected. Track in the tunnel gives trouble. The flow of the aggregate through the openings which are provided in the roof of the tunnel has to be relatively slow, because the materials are measured by the compartments into which they flow, and if any extra material is let down, there is difficulty in disposing of it. Moreover, in the nature of the case, a good deal of material over the tunnel has to be shifted from time to time to get it into a position from which it will flow to the batch boxes. As many as four men and sometimes more are used in loading the cars. On the whole, the tunnel has generally proved expensive and so has never been widely used nor is it likely to be.

Hoppers for Loading Trains.—The ordinary steel hopper, equipped with a volumetric measuring device, can turn out an accurately measured batch of sand and of coarse aggregate every 15 seconds, which is about as fast as the cars can be shifted to receive it. If this is deemed desirable, shorter legs can be used than are required when trucks are being loaded. As only one man is needed to operate the hopper, it is more economical than the tunnel in this particular. It, of course, costs a good deal less and, as it will load a train as promptly as it is ordinarily handled in a tunnel, is the more desirable loading device.

Loading Equipment Where Field Stock Piles Are Used.—Where material is transferred in bulk to field stock piles, the

standard material-yard equipment is modified by using hoppers without measuring devices, so that an unmeasured load of any desired size can be put onto the truck. At the stock piles loaders are then used to pick up the aggregate, elevate it, measure it, and deposit it in the batch trucks. These loaders have been developed to a point where they are durable, dependable, and efficient. They pick up the sand for a six-bag batch in about 20 seconds and the coarse aggregate for a batch in about twice that time. The batches are accurately measured, and the discharge is prompt. Their general use in paving work is not, however, likely because of conditions incident to field stock piling which affect the efficiency with which the trucks can be operated. These conditions will be fully discussed in the chapter on hauling.

Roads through the Material Yard.—The road through the plant should be graveled or otherwise so treated as to put it into good condition, after which it should be carefully maintained. There are few incidents in connection with the construction of a modern highway which appear more grotesque than the miring down of a paving contractor's trucks in his own material yard! Yet this happens repeatedly. The railroads commonly follow the valleys. Stations and sidings are often on low ground. So the effect of heavy rain is apt to be even worse in the material yard than it is on the road. As a result the road often can be used before the material yard has dried out enough to make conditions there satisfactory for the operation of trucks. A good deal of money now spent on heavy truck repairs would be saved if the roads through the material yards were built to carry heavy traffic under all weather conditions.

The Cement Storage.—Ordinarily cement is delivered in sacks and is handled by hand. As with the aggregates, the general practice is to move as much as possible from the cars to the mixer direct. A storehouse should always be provided, however, to absorb any delivery that is in excess of use and to provide some reserve supply in case use exceeds delivery. The desirable capacity of the cement storage sheds will depend somewhat on whether or not a uniform rate of production can be had at the mixer. On many jobs the rate of production varies a great deal, because the hauling equipment is adequate only when the haul is short. Under such conditions the contractor finds that, with a constant rate of delivery, cement accumulates when he is working at some distance from the mixer and that the surplus is

rapidly worked off when the haul is short. If work is conducted in this fashion, a relatively large storage capacity must be provided. But the work can be so regulated that the rate of production at the mixer is quite uniform. Under such conditions the storage capacity which is required is only such as is needed to absorb delivery during wet weather and to provide a small stock against any failure in the delivery to the material yard. Storage for 10,000 bags will cover all ordinary contingencies on a job where production is maintained at a high uniform rate but ought not to be much less even if a lower fluctuating rate of use prevails.

FIG. 26.—Loading platform at a well-arranged cement house of the ordinary type.

The rate of delivery that is asked for should be based on the actual amount of cement used over extended periods. If the rate of use, as an illustration, is pretty uniform at about 200 bags an hour, and if 220 hours of production per month are being had, 44,000 bags of cement will be needed. A delivery rate of 10,000 bags a week will then provide the desired supply. If, on the other hand, use fluctuates between 100 bags an hour on long haul and 200 bags an hour on short haul, averaging 150 bags an hour, a delivery rate of 7,500 bags a week would be adequate, but storage capacity could not reasonably be reduced below 10,000

bags because of the rate at which cement would accumulate during periods when the rate of use is low.

Practices in Handling Cement.—The practice in handling cement differs a good deal from job to job. Three distinct handling practices are in common use: (1) The cement is sent to the mixer on trucks which do nothing else and is there piled along the road (Fig. 27) and emptied by hand into the skip; or (2) the proper number of bags is thrown onto the batch trucks (Fig. 28) after the aggregate has been placed in them, the sacks being emptied onto the aggregate at the mixer just before the batch is dumped into the skip; or (3) the cement is emptied by hand onto the aggregate (Fig. 29) at the cement house. All of these methods are uneconomical. If the first method is followed, inspectors are apt to prohibit emptying the cement before the

FIG. 27.—Feeding cement to mixer from piles along shoulder.

aggregate is in the skip. The correct mixer cycle is 75 seconds; 10 seconds commonly are required to raise the skip, at least 5 to discharge it, and not less than 2 to lower it to the ground again. The average time used is more likely to be 20 seconds or longer than the 17 seconds which are actually required. The truck must then back in and dump the aggregate, an operation which may be performed in as little as 10 seconds, but one more likely to take at least 20 seconds. There are, then, some 30 to 40 seconds available during which the cement can be emptied without causing any delay, and the two men who commonly handle this work can do it easily enough within this time. But beside the fact that the expenditure of the time of two men on an operation of this kind is itself basically uneconomical, this practice in handling cement is objectionable because it makes operating condi-

tions too rigid. If everything is working perfectly, there is time enough. But if there is any delay in the delivery or if material sticks in the skip and so is not dropped as promptly as usual, or if there is trouble in dumping the truck, an endgate sticks, or any one of the endless little things which hold up production intervenes to delay depositing the aggregate in the skip, the 30 to 40 seconds which, with good operation, are available for dumping the cement, are reduced or dissipated entirely, with the result that a little time is lost. These losses appear small. Indeed, they are small.

FIG. 28.—Loading bags of cement into batch truck from a railroad car.

But if they average only 1½ seconds per batch handled, a batch is dropped every hour if production is at a high rate of efficiency. This is 10 batches a day and in its accumulation during a season's work involves a cost which makes a method of this sort prohibitively expensive.

Dumping the Cement on the Batch at the Mixer.—A better practice is to handle cement in sacks with the aggregate and to empty it onto the aggregate before the truck is dumped but, from the management standpoint, it is open to the objection that dumping the cement at this point is almost as uneconomical as dumping it according to the first method described. There is

also the objection that, in the event of any delay affecting the delivery of material, the delay in servicing the mixer is extended by the amount of whatever time is taken to empty the cement. Of course, this practice also causes the loss of an appreciable amount of truck time each trip. It commonly requires about a minute to empty the cement on a batch truck. If 40 batches an hour are being placed, holding each truck an extra minute in order to empty five or six sacks of cement causes the total loss of the time of two-thirds of a single-batch truck. It is the duty

FIG. 29.—Truck with full batch. Cement has been loaded and covered with sand.

of management to pick out and to eliminate losses of this sort, and any method which generates such losses ought to be replaced by a better one.

Dumping the Cement onto the Batch at the Yard.—Emptying the cement onto the trucks by hand at the cement house is almost equally expensive. It saves the appearance of delay in servicing the mixer, but, as it ordinarily takes about a minute to put the cement onto a truck in this way, the loss of truck time is almost as great when the cement is dumped at the cement house as when it is dumped at the mixer. Some advantage is, of course, had

from the fact that the cement is, by this practice, handled only once, whereas the other systems involve handling it again in the field, and a little additional advantage is had from the fact that the sacks are retained at the cement house; thus the loss of sacks is less and the cost of collecting them is reduced. It is not, however, an efficient method of handling cement.

Mechanical Methods for Handling the Cement.—In the last analysis all of these methods are, then, uneconomical and ought to be abandoned. To just what extent they are uneconomical

FIG. 30.—Using wheelbarrows for feeding the mixer. This method of handling the aggregate has gone out of vogue. The efficiency of operation ordinarily was low.

may perhaps be best illustrated by observing that on most jobs five or six men are employed in handling cement, whereas but three or four—a craneman, one or two laborers on the cars, and a hopper operator—handle the aggregate which weighs more than five times as much!

The use of mechanical means for handling cement would much improve this department of the work. Whether special compartments ought to be required if the cement is handled loose as part of the batch is, from the construction standpoint, rather an unimportant detail. The important considerations are the reduction of the amount of labor required and the reduction of

FIG. 31.—Belt conveyor moving cement from car to loading platform.

FIG. 31*a*.—The belt conveyor moves the cement from the cement house door on the car side to the loading platform. There it is dumped into a hopper the lower part of which can be seen over the truck body, to be discharged onto the aggregate already in the truck.

the time that the trucks are delayed by the present practices in handling the cement.

One method which has been tried and found satisfactory in dealing with the cement-handling problem is to install a portable belt conveyer (Fig. 31) in the cement house, using this to elevate the sacked cement to a point high enough so that it can be emptied into hoppers and the hoppers discharged by gravity into

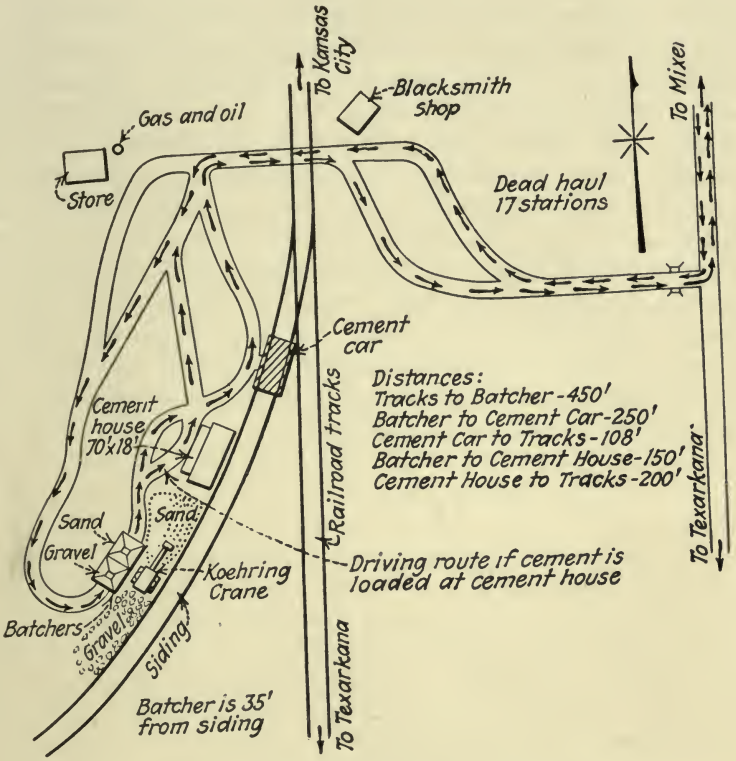


FIG. 32.—A good material yard layout.

the trucks. Three men can operate an installation of this kind: one to bring up the cement either from the car or from storage, one to feed the conveyer, and one to empty the sacks and discharge the hopper. The five or six bags required for a batch can be handled in about 1 minute; so if the trucks are properly spaced, the delay due to taking on the cement can be made very small, as the cement can be run into the hopper between the servicing

of one truck and the arrival of the next. Probably a weighing device similar to that used in handling aggregate could be rather easily installed, which would be faster than the belt conveyer and would require one less man. But until such a machine is developed, the belt conveyer offers the best means available for solving the problem of reducing labor and truck time losses in this field.

The Yard Layout.—Figure 32 gives an ideal material-yard layout. Field conditions will necessarily impose many variations from such a layout. The principle involved is the elimination of lost time by providing for a straight drive through the yard. Backing takes time. So do long moves between service points. The whole set up in the material yard should be business-like. A haphazard yard with homemade hoppers, a tumbledown cement shed, and a general appearance of careless inefficiency leaves an impression on the men who work about the yard and on those who must drive through it which encourages similar laxity in their work. But even if this were not so, a careful yard design, the elimination of all backing, the creation of good driving conditions, and a general ease of operation will save enough time much more than to offset the attention and the cost that its creation ordinarily requires.

CHAPTER VII

THE PROPER TRUCK SUPPLY

The standard method of delivering materials and the one ordinarily most economical, most efficient, and most satisfactory, when the materials can be secured at a common point and the haul does not exceed some 5 or 6 miles, is direct delivery from the material yard to the mixer in batch trucks. This method is basically economical, for no rehandling of materials is involved, and the truck time per ton of material moved, equal efficiency of operation under both systems being assumed, is less than where field stock piling is done. Indeed direct delivery by truck is the most widely and most generally used, as well as the most generally successful method of delivering materials now in vogue. It will never be universally adopted, however, for, when the haul is long, the management of the trucks becomes an outstandingly difficult task. Moreover, in order to handle long hauls efficiently the number of trucks becomes inconveniently large, so that if owned trucks are used, standby costs become excessive. If, on the other hand, trucks are rented, the cost is high and the management of the work is rendered even more difficult. The operation of this system of material delivery is not, therefore, without its problems, especially when unusual conditions must be met, but, because for ordinary haul distances it is basically the most economical system of delivery as well as the system under which high efficiency can be most easily developed by good management, its adaptability to any given job should be thoroughly considered before any other system is adopted.

Formulae for Trip Time.—Almost any style of truck may be used for this work. The most common type is the single-batch truck. If these are to be used, the number required can be calculated for any haul distance by the use of the formula $T = 4 + 8d$, in which T is the time required in minutes for a round trip from the material yard to the mixer, and d is the distance in miles from the material yard to the mixer. The 4 in this formula has been derived from data collected during numer-

ous observations on servicing the trucks, that is, putting on aggregate and cement, manipulating the trucks in the yards, passing them through the turntable, and backing them to the mixer. The 8 in this formula results from the ordinary safe operating speed for these trucks, which is about 15 miles an hour.

The formulae for other types of trucks are as follows:

For two-batch, heavy-duty trucks..... $T = 6 + 10d$ (1)
For three-batch, heavy-duty trucks..... $T = 8 + 10d$ (2)
For four-batch, heavy-duty trucks..... $T = 10 + 10d$ (3)
For two-batch, high-speed trucks..... $T = 6 + 6d$ (4)

All of the above formulae are based on first-class loading plants and assume that cement will be sent out on the truck as part of the batch. If the cement is sent out by itself, the constant in these formulae can be reduced from 1 to 3 minutes, depending on the number of batches the truck carries.

Effect of Stock Piling on Rates of Delivery.—For single-batch trucks which are used in handling stock-piled materials, the formula $T = 6 + 8d$ should commonly be used instead of the formula $T = 4 + 8d$, which gives the trip time only when the loading is done in a well-designed material yard. This difference, which may easily amount to the full time of more than one truck, is due to the fact that where the loading is from stock piles, the loaders have to move about to reach the material, for it is obviously impossible to move the material to the loaders. On this account there cannot, in the nature of the case, be any fixed route through the material yard. Moreover, it often happens that, during a good deal of the time, the trucks must be backed to reach one or both of the loaders. Of course, manipulation of this kind takes time, with the necessary result that the round-trip time of the trucks is increased and the number of loads taken out per truck per day, particularly on short haul, is reduced. It has also been frequently observed that the water which falls on field stock piles during heavy rains keeps the ground under them so wet that trucks often mire down in working around the loaders. This of course causes a good deal of lost time.

For two-batch, standard trucks the formula for delivery from stock piles to the mixer is $T = 8 + 10d$; if high-speed trucks are used, $T = 8 + 6d$.

Effect of Road Conditions on Delivery.—If road conditions are adverse, as they are apt to be where delivery is over the uncovered

subgrade, even the best-handled trucks may find it impossible to maintain the average speed on which these formulae are based, in which case the factor representing their speed must be adjusted. Thus, for high-speed trucks operating over poor roads, the factor 6*d* may change to 7*d* or even to 8*d*. Similarly, if road conditions are very good, this factor may drop to 5*d* (24 miles an hour) or in some cases to 4*d* (30 miles an hour). Very good road conditions are necessary, however, if such speeds are to be justified, and as a matter of ordinary practice, it is better for each type of truck to operate at or near the speed on which the standard formula is based. High speed causes the trucks to wear out rapidly even when the roads are good and is highly destructive when the roads are in bad condition. It may also be observed here that both efficiency and economy in operation dictate that a proper driving speed be established and that the trucks be rigidly held to that speed. Indeed, it is practically impossible to work out a proper truck supply or to control the operation of the trucks on any other basis. The formulae given above are based on safe rates of speed, and these rates seldom should be exceeded.

Number of Trucks Required for Various Hauls.—Table IV gives the number of trucks of various types needed in delivering batches from a well-equipped material yard to the mixer over ordinary haul distances, if the trucks are driven at standard speed and the mixer is turning out 40 batches an hour. In the nature of the case, other rates at the mixer would generate a different table of trucks required. No error of consequence will result, however, if a percentage correction factor is applied to this table where either higher or lower rates of output at the mixer prevail.

TABLE IV.—NUMBER OF TRUCKS REQUIRED FOR VARIOUS LENGTHS OF HAUL WITH PRODUCTION AT 40 BATCHES AN HOUR

Haul, miles	Heavy duty[1]	Single batch	High speed
1	6	8	4
2	9	13	6
3	12	19	8
4	15	24	10
5	19	29	12
6	22	35	14
7	29	40	16
8	29	45	18

[1] Two batch.

With the haul known, as it necessarily is at any particular time and place, the time required for a round trip at that distance can be readily determined for the style of truck in use from whichever one of the above formulae applies. By dividing the time required for a round trip into the number of minutes in the working day, the number of trips which a truck can make will result. Fractional trips must be dropped, as they will not be run. Having the number of trips that a truck can make each day, the number required at that haul distance may be found by dividing the scheduled production in batches per day by this figure. To the required number of trucks as determined in this way should be added such extra trucks as may be needed to offset the effect of any small delays occurring as a result of accident or indifference in handling the material supply. The effect of delays is discussed at greater length on page 115. The superintendent should proceed in this way in the day-to-day calculation of the number of trucks needed in order to provide a material supply which is sufficient to enable the mixer to meet the scheduled production. Incidentally, perhaps it would not be inappropriate to remark that the use of more than the number of trucks these formulae show to be necessary, plus a reasonable margin to enable the fleet to avoid the effect of minor delays, is both expensive and inefficient. It has often been observed that the whole of a fleet of trucks is used without regard to the length of haul. Too much can hardly be said in condemnation of such a practice.

Determining the Number of Trucks for the Job.—It is one thing to determine the day-to-day demand for trucks as the haul varies, but to determine the number of trucks which ought to be sent to a given job as adequate hauling equipment for that job is quite a different matter. This involves not only the length of haul prevailing on that particular job, but also the length of haul ordinarily encountered on concrete jobs in the general territory where the contractor is working, the possibility of using extra trucks on other work, the cost of owning standby equipment, etc. A modern heavy-duty truck, for instance, will cost from $4,000 to $5,000. The yearly interest on this sum will amount to perhaps $300. Dead storage, it may be assumed, will cost $100 a year, and taking the truck to and from the job another $100. In the nature of the case, these figures are suppositious, for the original cost of such trucks varies, interest rates vary, and jobs are not all an equal distance from headquarters. How-

ever, the contractor who is endeavoring to determine what truck supply he can afford to own will know what these figures are in any individual case. For the moment it may be assumed that they generate a yearly standby cost of $500 for each extra heavy-duty or high-speed truck sent out to the job. To be a profitable investment, there must be reason to assume not only that the savings likely to develop from having standby trucks on the job will cover this charge in addition to depreciation, repairs, operating cost, and a profit while these trucks are held on the job at the moment in hand, but that they normally can earn carrying charges and a profit from year to year. In short, it is not sufficient to justify purchasing the trucks on the basis of the business in hand. The justification must rest on the business normally handled and on the rate at which this business appears to be increasing.

Factors in Truck Operation.—Now, it will be apparent that while the cost of hauling, when considered as an operation by itself and without reference to overhead, is affected by the efficiency with which it is done, it is not affected by the number of transportation units employed. In other words, if there are 1,000 hours of two-batch truck time involved in a given operation, the hauling cost per truck-hour remains constant whether the work is done in 100 days by 1 truck working 10 hours a day or whether it is done in 10 days by 10 trucks each working 10 hours a day. Moreover, it may be reasonably assumed that the returns received from whatever work is done by any truck will pay for depreciation, repair costs, operating charges, etc., and will yield a profit which is reasonable in view of the time worked. But not all of the trucks employed on a concrete paving operation are worked full time. If correct operating methods are followed, some will be in actual use only a small part of the time, and with respect to each of these there is a short time when the truck is profitably employed and a longer period when it is idle. But while the number of trucks used does not affect the direct cost of hauling, it does affect the amount of time during which the mixer can be worked to full output capacity. The question as to what hauling equipment should be supplied to a given job resolves itself, then, into a matter of determining how far the increased output of the mixer made possible by having such trucks available is likely to be large enough to cover the standby charges on hauling equipment used only a part of the time and still

show a profit to the owner sufficient to justify the capital outlay involved.

Time Savings Required to Justify Standby Trucks.[1]—It has been shown that mixer time is worth about 70 cents per minute. Therefore, any saving in mixer time which will, at this rate, exceed the assumed standby cost of $500 a year will render the ownership of standby equipment profitable; or in other words, if having an extra truck will enable the mixer to operate more than 714 ($500 divided by 0.70) minutes during a working season when it would otherwise be idle, the savings on payroll, equipment depre-

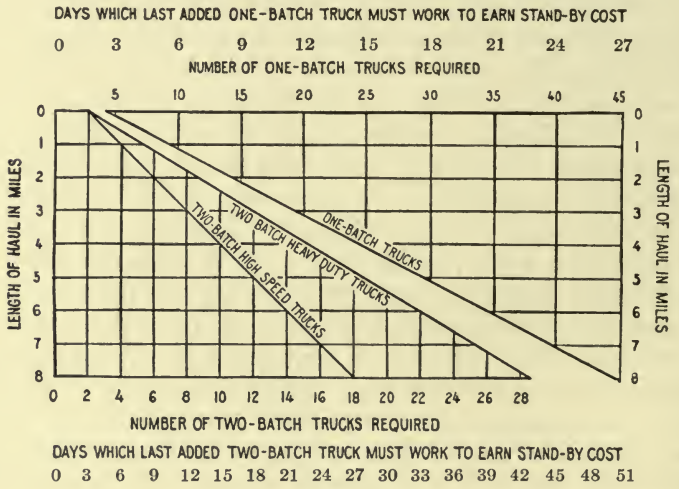

DAYS WHICH LAST ADDED ONE-BATCH TRUCK MUST WORK TO EARN STAND-BY COST
0 3 6 9 12 15 18 21 24 27
NUMBER OF ONE-BATCH TRUCKS REQUIRED
5 10 15 20 25 30 35 40 45
LENGTH OF HAUL IN MILES
0 1 2 3 4 5 6 7 8
ONE-BATCH TRUCKS
TWO BATCH HEAVY DUTY TRUCKS
TWO-BATCH HIGH SPEED TRUCKS
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
NUMBER OF TWO-BATCH TRUCKS REQUIRED
DAYS WHICH LAST ADDED TWO-BATCH TRUCK MUST WORK TO EARN STAND-BY COST
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51

FIG. 33.

ciation, and miscellaneous costs, etc. thus effected will offset the truck standby charges. As in 714 minutes the full production of the mixer would be 571 batches, any production in excess of this amount made possible by having the extra truck would generate a net profit, and if such a saving can be expected to accrue from year to year as the natural result of ordinary operation, the desirability of having the extra equipment is apparent. From the theoretical standpoint, therefore, the problem is reduced to the simple one of determining whether an extra truck would increase output more than 571 batches a year. It makes

[1] In previous discussions of this matter, operating expenses, overhead, miscellaneous costs, etc. have been purposely ignored.

no difference whether these 571 batches are hauled in one working period or in a number. The question is solely one of whether the truck commonly would enable the mixer to do this additional amount of work during an ordinary working season.

Savings in Time Which Can Be Made at Various Haul Distances.—In practice, trucks sent out as standby equipment are called into regular service only on the longest haul, which means that they will be used only for short periods. The analysis will,

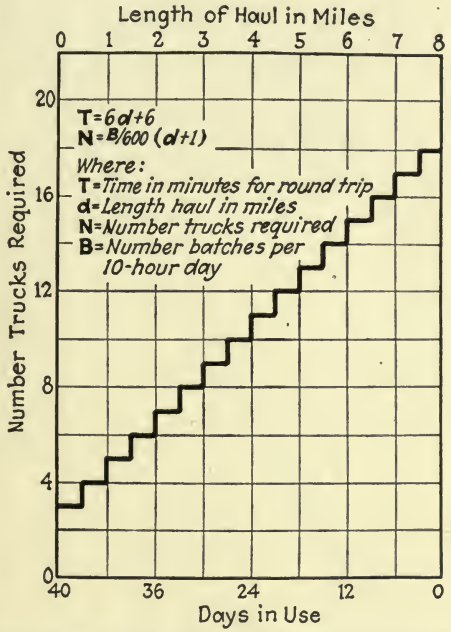


FIG. 33*a*.—Number of two-batch high-speed trucks required on various lengths of haul, to deliver 40 batches an hour.

therefore, be continued on that assumption. Thus, a 4-mile haul by a heavy-duty, two-batch truck requires 46 minutes (see formula (1)). At that distance, therefore, such a truck will haul 13 loads per 10-hour day; and as two batches are hauled at each load, the day's haulage will be 26 batches, and 22 days' work will be required to haul 571 batches. In a similar manner, it can readily be ascertained that 17 days will be required to haul 571 batches when the haul is 3 miles, and 29 days when the haul is 5 miles. If, then, the requirements are commonly such that

there will be 17 days' work on a 3-mile haul, or 22 days on a 4-mile haul, or 29 days on a 5-mile haul, the standby cost will be covered by savings in payroll, operation and depreciation, overhead costs, etc., which will result from the more intensive opera-

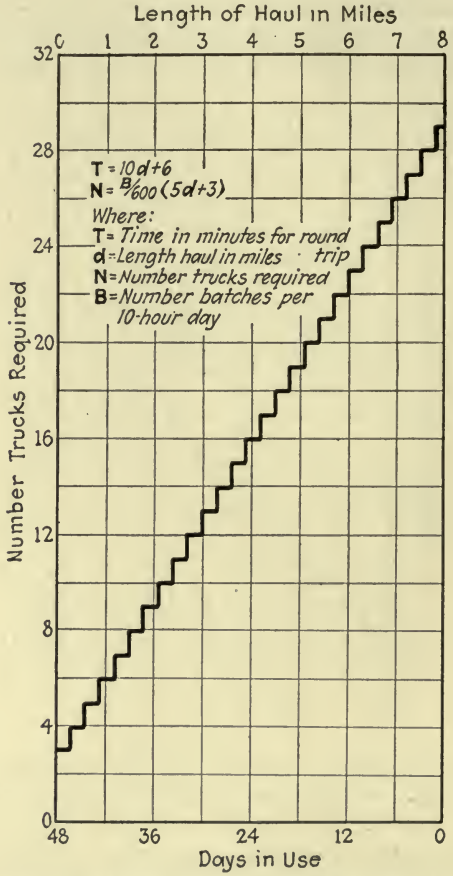


FIG. 33b.—Number of heavy duty two-batch trucks required for various lengths of haul, to deliver 40 batches an hour.

tion of the mixer, and if more than this time can be worked, a profit accrues. In making this analysis, it is assumed that while at work the truck is efficiently operated and is making a fair profit, and that while in dead storage it is so well cared for that it does not deteriorate.

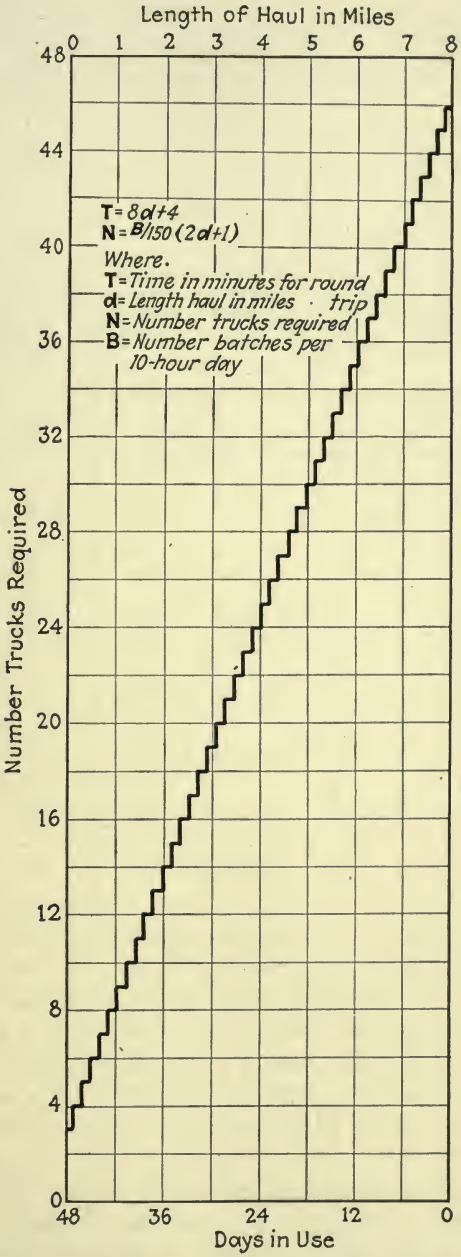


FIG. 33c.—Number of single-batch trucks required for various lengths of haul, to deliver 40 batches an hour.

The development of this phase of the transportation question from the standpoint of the single-batch truck would be based on a computation of the standby cost somewhat as follows:

Interest	$ 50
Dead storage	50
Cost of getting to and from the job	100
Annual standby cost	$200

In this case the saving of only 285 minutes of mixer time, *i.e.*, the delivery of 230 additional batches, will offset the standby cost. This is equivalent to the delivery to and the utilization by the

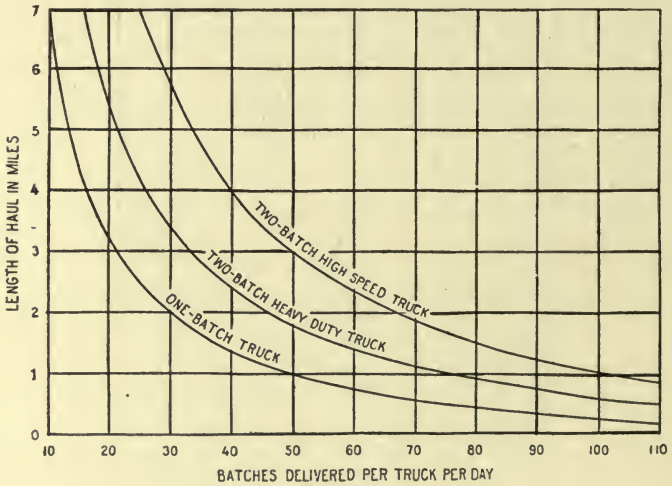


FIG. 34.

mixer of the batches that such a truck can haul 3 miles in 11 days, or 4 miles in 14 days, or 5 miles in 17 days. For two-batch, high-speed trucks the standby cost is about the same as for two-batch, heavy-duty trucks, but the delivery per day is higher. The purchase of an additional truck is justified (by the method used above) if it can be fully utilized for only 11 days on a 3-mile haul, or 15 days on a 4-mile haul, or 18 days on a 5-mile haul (see formula (4)).

The Relation of Earnings to Standby Cost.—The foregoing analyses could be extended to allow for the reduction in total standby cost, which might properly be made when a truck is put in service. Thus, trucks used as hauling equipment on concrete

highway construction ordinarily must be assumed to earn capital charges, cost of delivery to and from the job, winter storage, and profit for the whole year, in addition to depreciation and operating expenses while working, within the 6 to 8 months during which they are normally operated. If, then, a truck will have 3 months' work, it should, during that period, cover at least half of the standby cost noted above, out of normal earnings. There is, however, no need to consider this phase of the matter further or to include it in subsequent calculations, because it is perfectly clear that trucks which are to be operated over as long a period as this should be supplied in any event, as otherwise mixer operation will fall to an obviously inefficient point. The problem as a contractor faces it is one of determining when the purchase of another truck to cut down losses of time at the mixer ceases to be advisable. When this point is reached, the time the truck will work is so short that the amount by which the standby cost would be offset by the earnings of the truck when actually at work is less than the probable error involved in the calculation of the standby cost. For that reason it should be ignored in determining whether another truck ought to be supplied.

Prevailing Haul Distances.—Two problems then present themselves: What is the ordinary maximum length of haul on a concrete paving job, and how does this usual maximum haul affect the use made of the trucks? Unfortunately a sufficient amount of data is not at hand to answer the first question as fully as would be desirable. On the jobs which the author has studied, a maximum haul of 5 miles has been found to be rather common while hauls longer than this have been rare. This may, then, be taken as a reasonable basis for a further analysis of the transportation problem, and because there are very few superintendents who are able to synchronize so completely the various operations involved in laying a concrete pavement as to obtain consistently an output of more than 40 batches an hour, even under a specification allowing a 1-minute mix, this will be used as the basis from which to work. It will, of course, be understood that the details of any analysis such as this must be modified by anyone who is using it to meet the best performance he is able to secure.

To obtain an answer to the second question, the mix and the cross-section must be known. In the further analysis of this problem it will be assumed that one batch (five bags) yields 2¼ lineal feet of pavement. On this basis, the output per 10-hour

day should be 900 feet. If this rate of production is maintained, a mile of concrete paving will be laid every 5.8 days, which, for

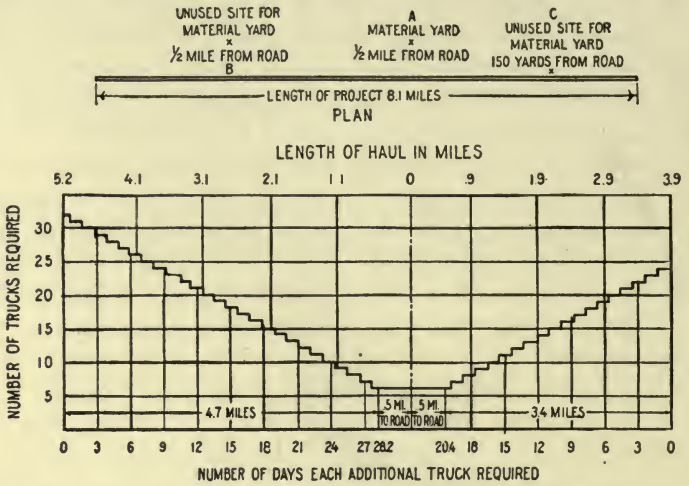

UNUSED SITE FOR MATERIAL YARD
½ MILE FROM ROAD
B
A
MATERIAL YARD
½ MILE FROM ROAD
C
UNUSED SITE FOR MATERIAL YARD
150 YARDS FROM ROAD
LENGTH OF PROJECT 8.1 MILES
PLAN
LENGTH OF HAUL IN MILES
5.2 4.1 3.1 2.1 1.1 0 .9 1.9 2.9 3.9
NUMBER OF TRUCKS REQUIRED
30 25 20 15 10 5
4.7 MILES
.5 MI. TO ROAD
.5 MI. TO ROAD
3.4 MILES
0 3 6 9 12 15 18 21 24 27 28.2 20.4 18 15 12 9 6 3 0
NUMBER OF DAYS EACH ADDITIONAL TRUCK REQUIRED

FIG. 35.—Graphical representation of hauling as actually done.

the purpose of simplifying this discussion, will be called 6 days. A full truck supply for this rate of production (40 batches per

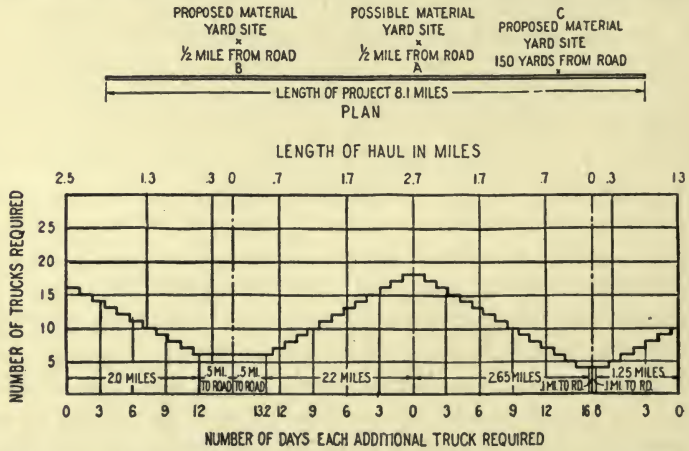

PROPOSED MATERIAL YARD SITE
½ MILE FROM ROAD
B
POSSIBLE MATERIAL YARD SITE
½ MILE FROM ROAD
A
C
PROPOSED MATERIAL YARD SITE
150 YARDS FROM ROAD
LENGTH OF PROJECT 8.1 MILES
PLAN
LENGTH OF HAUL IN MILES
2.5 1.3 .3 0 .7 1.7 2.7 1.7 .7 0 .3 1.3
NUMBER OF TRUCKS REQUIRED
25 20 15 10 5
2.0 MILES
.5 MI. TO ROAD
.5 MI. TO ROAD
2.2 MILES
2.65 MILES
.1 MI. TO RD.
.1 MI. TO RD.
1.25 MILES
0 3 6 9 12 13.2 12 9 6 3 0 3 6 9 12 15.8 3 0
NUMBER OF DAYS EACH ADDITIONAL TRUCK REQUIRED

FIG. 36.—Graphical representation of amount of hauling that would have been required had yard sites B and C been used.

hour) for various lengths of haul was given in Table IV. Figure 33 gives the number of days' work required of a truck in order that savings at the mixer shall offset standby cost, the possible

saving due to additional trucks being figured at 1¼ minutes per batch delivered at the mixer. Figure 34 develops graphically the data on truck delivery capacity.

To obtain an idea of the use which will be made of the trucks sent to the job, a graphical analysis of the haul conditions which will prevail and the truck supply which will be needed should be made in the general style used in Figs. 35, 36, and 37, which were drawn from the layout data for one of the jobs recently studied. These particular graphs are drawn to a vertical scale in which one division equals one single-batch truck and a horizontal scale[1] in which one scale division equals 1 mile or 6 days,

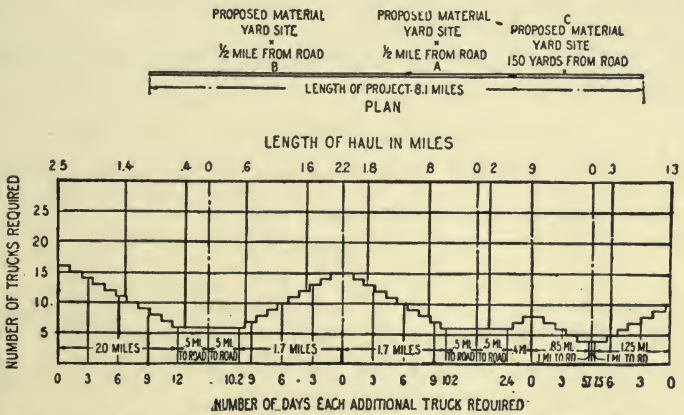

PROPOSED MATERIAL YARD SITE B ½ MILE FROM ROAD
PROPOSED MATERIAL YARD SITE A ½ MILE FROM ROAD
C PROPOSED MATERIAL YARD SITE 150 YARDS FROM ROAD
LENGTH OF PROJECT-8.1 MILES
PLAN
LENGTH OF HAUL IN MILES
NUMBER OF TRUCKS REQUIRED
20 MILES
1.7 MILES
1.7 MILES
NUMBER OF DAYS EACH ADDITIONAL TRUCK REQUIRED

FIG. 37.—Graphical representation of amount of hauling that would have been required had all three yard sites been used. In Figs. 35, 36 and 37 the amount of hauling in the area below the stepped line.

6 days' time being required by the above assumptions to lay a mile of pavement. If another style of truck had been used, the vertical scale would, of course, have had to be modified accordingly.

To draw a chart of this sort, after selecting appropriate horizontal and vertical scales, first lay off the dead haul, that is, the distance from the plant to the road. Then, by calculation or from some figure, as Fig. 34, determine the minimum number of trucks required to handle the dead haul, which determines the minimum truck supply for that set-up. The dead-haul distance and the minimum truck supply having been determined and plotted (see Fig. 35), the stepped line giving the points at which another truck must be added may be obtained from such a

[1] The horizontal scale divisions are not shown.

figure as Figs. 33*a*, 33*b*, and 33*c*, or calculated from the formula for the distance over which any given number of trucks can make a full delivery of materials.

It may be interesting to observe here that the graph in Fig. 35 shows how a contractor actually hauled materials for this job. Figures 36 and 37 show other possible ways of handling this job and indicate both that the contractor's set-up required more trucks than were really needed to deliver the materials, and that the cost of hauling the materials was considerably increased over what it should have been.

Formulae for Calculating Truck Supply.—The formulae which have been used in developing the graphs appearing with this chapter were derived as follows:

For high-speed, two-batch trucks the time required per load (formula (4)) is

$$T = 6d + 6$$

As in a 10-hour working day there are 600 minutes, L the number of loads hauled per truck per day $= \dfrac{600}{6d + 6}$

or

$$\frac{100}{d + 1}$$

If N equals the number of trucks, the total number of loads delivered during a working day (100 per cent efficiency in truck operation being assumed) becomes NL

or

$$N\left(\frac{100}{d + 1}\right)$$

And as these are two-batch trucks, the number of batches deliverable per day is

$$2N\left(\frac{100}{d + 1}\right)$$

Now let Y equal the number of batches a day needed in order to meet regular mixer requirements.

Then, if Y, the scheduled production of the mixer, equals $2N\left(\dfrac{100}{d + 1}\right)$, that is, if the total delivery just equals mixer requirements, a solution of the equation for d will give the maximum distance over which full delivery can be made with any given number of trucks.

In solving this equation the value of Y is known. For 100 per cent production at the mixer and a 1-minute mix, it is 480 batches. Ordinarily, the scheduled production will be somewhat less than this, perhaps 460, 450, or even 400 batches a day. Figures 33 to 37, inclusive, were drawn under the assumption that the scheduled production is 400 batches a day. For any other requirement the graphs would be modified accordingly. In drawing graphs such as those shown, the value of N will, of course, be varied from the number of trucks required for a zero haul to the highest number required to obtain full production against the longest haul on the job. In plotting it should be remembered that the solution of this equation gives the longest haul against which full delivery at the assumed rate can be made by the assumed truck supply, in other words, the point at which another truck should be added.

The above development covers high-speed, two-batch trucks only. A similar development for heavy-duty, two-batch trucks yields the formula

$$Y = 2N\left(\frac{300}{5d + 3}\right)$$

For heavy-duty, five-batch trucks, the formula is

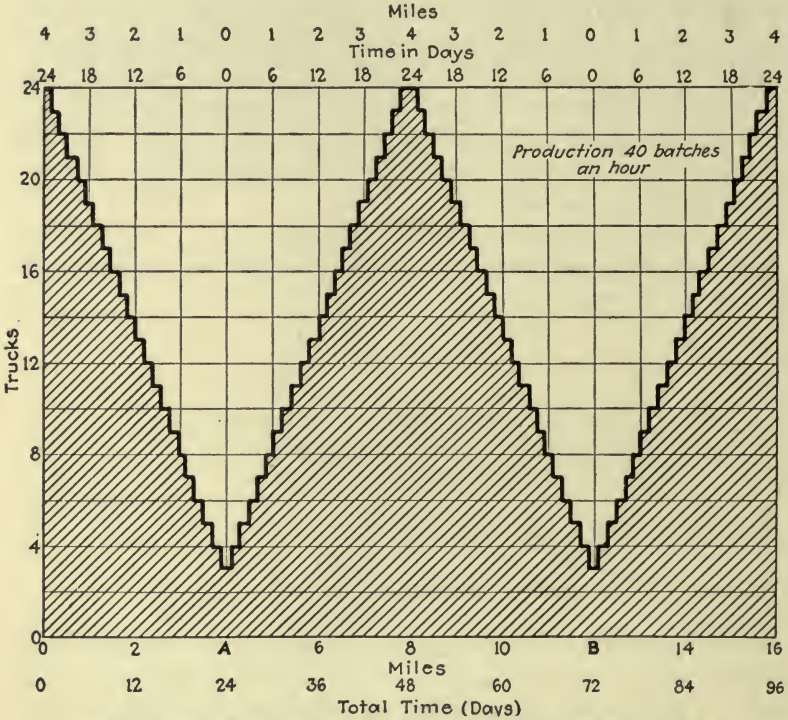
$$Y = 5N\left(\frac{300}{5d + 7}\right)$$

For single-batch trucks the formula is

$$Y = N\left(\frac{150}{2d + 1}\right)$$

Time Each Truck Will Work on a Given Job.—It is now possible to make a further analysis of the standby equipment problem. Thus, taking at random, for example, a 16-mile job (see Fig. 38) which is to be handled from two plant set-ups, from both of which the haul in each direction will be 4 miles, it is apparent from the graph for two-batch, high-speed trucks that as two trucks are required at zero haul, the third must be added before full delivery of material can take place at any haul beyond the zero point. The minimum truck supply is for the assumed rate of production, therefore, three trucks. These must remain in service as the haul distance increases, that is, until the maximum distance of 4 miles is reached. But 4 miles in distance has been shown above to be equal to 24 days in time. To perform

the work on this 4-mile leg, these trucks must, therefore, work 24 days, and as the project is, by the assumption originally made, composed of four such legs, these trucks must perform 96 days' work. By a similar process of reasoning the fourth truck, required when the second half of the first mile is reached, will work 84 days, and of the two additional trucks needed to make full delivery over the next mile, one will work 72 days and one



A and B, material yard setup. Truck time shown by cross hatched area.

FIG. 38.—Single-batch truck supply and truck operating time for a sixteen mile paving job.

60 days. The next two trucks will work 48 and 36 days, respectively. The number of days each of these trucks will be employed is so large that there is no question that they must be used, for without them mixer output would fall below schedule too much of the time. The real problem arises in connection with the next two trucks, those needed to secure full delivery only against the 3- to 4-mile haul. Theoretically, one of these will have 24 days'

work to do and the other only 12. Of the time worked by the first, 18 days will be required, under the assumptions used above, to offset standby cost, and for the same purpose 20 days' work would be required of the second. Without these trucks, the mixer efficiency would be reduced from 100 per cent at the end of the third mile to 80 per cent at the end of the fourth. If neither of these last two trucks is provided, therefore, the loss on payroll, equipment operation and depreciation, overhead, etc., costs could not exceed an average of 10 per cent, or about $40 a day, over the period of 26.6 days which would be required in performing this work, that is, laying 4 miles of pavement at the reduced rate of production—a loss of a little over $1,000.

Effect of Purchasing Last-needed Trucks.—If one truck is purchased, payroll, and depreciation losses would be reduced to an average of 5 per cent, or $20 a day, over a period of about 12.6 days—about $250. On this job, therefore, the ninth truck would produce a saving of $750, against which there must be charged the standby cost of $500, a net saving of about $250; while the purchase of the tenth truck would save $250, against which there would be the same standby cost of $500, a net loss of $250.

Insurance Value of Trucks.—If these were the only consideration, the answer would be clear; the tenth truck would not be justified, and the ninth, while justified, would not earn enough to encourage a contractor to own it unless he had ample resources. But these are not the only matters involved. A more important consideration is the fact that an efficiency of 100 per cent in the operation of trucks is almost never obtained. If, for example, only eight trucks were available for this work, there would be a period of at least 48 days during which it would be impossible to provide both a standby truck against emergencies and an extra truck in operation which practical experience has demonstrated is necessary if the innumerable small delays and occasional breakdowns encountered in truck operation are not to affect the output of the mixer. If the ninth truck is purchased, the period when there will be neither an extra truck in the train nor a standby truck will be reduced to 24 days. Just what insurance a contractor should have against truck delays will depend somewhat on what he can afford. The ninth truck will carry itself; so the insurance it gives against day-to-day losses of one sort and another really costs him nothing. Therefore, it cer-

tainly ought to be procured. The tenth does not carry itself and has reduced insurance value. To own it is not as certainly profitable, but as with other forms of insurance, its cost may serve to avoid more serious loss.

Final Conclusion.—For jobs of this character, it may, then, be accepted as a general rule that it is wise to provide just the trucks needed to meet the longest haul prevailing, unless this haul exceeds the ordinary maximum for that general region. Moreover, it also is well to make definite plans to insure that when the long haul is reached, every available truck will be in such perfect condition and the driving so carefully supervised that during the brief period when all of the transportation equipment is needed, the highest possible efficiency will be obtained. Every contractor will understand that on a job of this kind the period of long haul almost invariably follows a period of short haul, during which any trucks needing the services of a mechanic can be attended to without delaying the material delivery.

Renting Trucks for Extra-long Haul.—On the other hand, there is the occasional job where the maximum haul will considerably exceed the maximum of the average job. To buy a full truck equipment for a job of this sort would, in theory at least, leave the contractor at the end of the job with a number of trucks on which, in ordinary years, he could not reasonably expect to earn even the standby cost. In a case of this kind, though special conditions may suggest a different treatment, the contractor's safest policy ordinarily lies in furnishing the number of trucks normally required in the region where he operates, and renting the additional trucks needed for the extra-long hauls. While it is advisable that the hired trucks be uniform in general characteristics with the others used on the job, this is not necessary. Rented trucks should be hired when needed and laid off as fast as the haul distance shortens. If they are hired only when the haul is long, and that fact is fully understood by the owner, the scheme can be made to work very well. Trucks hired only for short periods are apt to cost a little more than trucks hired for the whole job, but this is not likely to be a matter of much consequence.

The Problem Involved.—The solution of the problem of hiring extra trucks for long haul is covered in the following illustration. The conditions on a certain job are such that the mixer must start 6 miles from the batch plant. With a full truck supply

this mixer has been producing 40 batches an hour. The contractor, having found that 4 miles is his customary maximum haul, has available only 15 heavy-duty, two-batch trucks. But 22 such trucks are needed to deliver 40 batches an hour to the mixer against the 6-mile haul. What can he afford to pay for the 7 extra two-batch trucks or the 11 single-batch trucks that he will require to maintain his customary rate of production against the 6-mile haul?

In the first place, if 22 trucks are required for a delivery of 40 batches an hour, 15 trucks can deliver only a little over 27 batches an hour. But 40 batches per hour is an 83.3 per cent utilization. A full truck supply will, therefore, mean a saving of 27 per cent of the working day (which in this discussion is assumed to be 10 hours long), or 162 minutes, worth on the basis previously deduced, approximately $115. The contractor has enough trucks to maintain his customary production up to a 4-mile haul. There are, therefore, 2 miles over which losses in mixer time due to an inadequate truck supply will, if no trucks are added, range from zero at 4 miles to $115 a day at 6 miles, an average of $57 per day. It has previously been shown that, at 40 batches per day, laying a mile of ordinary concrete road takes about 6 days, but laying it at the rate of 27 batches will require about 9 days. The time required to lay the 2 miles farthest removed from the batcher plant will, then, if no additional trucks are employed, be about 15 days. Having an adequate truck supply for this work should, therefore, be worth $57 a day for each of 15 days, or about $850. Now, as the cost of hauling is not affected by the number of units used in performing the haul, the contractor can save all of the $850 if he can employ extra trucks at a rate no higher than the cost of using his own trucks. If he has to pay a higher rate than he allows himself for his own trucks, the difference merely reduces the saving possible from operation on a basis of normal production. If the difference is greater than the possible saving—in this case $850—renting trucks to maintain production would be unprofitable.

The Type of Truck to Use.—The above discussion indicates the basis on which a sound decision as to the number of trucks that ought to be furnished to a given job may be made. It is not as easy to establish a rational basis on which to rest a decision as to what type of truck is best suited for this work. There are a number of reasons for this, of which the different effect of different

types of trucks on the subgrade may be cited as perhaps of most importance. Heavy trucks, heavily loaded, can make occasional trips safely over earth roads which would not carry such loads in large numbers for any considerable period. Then, too, the paving season is short at the best, and there are many regions in which at least portions of the soil are of such a nature that stability is not reached until late in the fall, if, indeed, it is reached at all. It is quite unavoidable that some of these unstable soils should get into the subgrade over which paving is to be done, and that wherever they occur, heavy trucks should cause rather deep rutting. In the worst cases this results in such displacement of subgrade materials that an acceptable subgrade is almost impossible to secure, forms are thrown out of line, and grade and conditions about the mixer are rendered generally unacceptable to the engineer who feels that a high-class pavement ought to be laid with care on a subgrade which is in such condition as to establish confidence that it will act as a proper support for so valuable a structure. The very heavy trucks, those carrying three or more batches, have in short been limited in their scope by reason of the damage which they have done to the subgrade and of the fact that no way has been devised to correct this damage to the satisfaction of engineers. Over the greater part of the country a contractor is, therefore, in practice at least, limited in his selection of batch trucks to the single-batch and the two-batch types. Even then the effect on the subgrade cannot be ignored, for the introduction of the six-bag mixer has raised the weight of a single batch, cement included, to so close to 2 tons that for all practical purposes it may be considered a 2-ton load. Trucks are commonly designed to carry some overload, but the planetary transmission type which has been the popular single-batch truck is obviously overloaded when called on to carry the six-bag batch. The gearshift trucks of about the same size appear not to be quite as badly overloaded but it is hardly safe to say that there is now on the market any cheap truck of the single-batch type which ought to be called on to carry a 2-ton load over the roads commonly found between the material yard and the mixer. Designs change rapidly in the truck field, and so this condition may change at any moment; but the contractor who purchases for this work single-batch trucks of any of the ordinary varieties now on the market will unavoidably find that his rate of depreciation is high.

Two-batch Trucks.—On the other hand, both the weight and the cost of the two-batch trucks are high. Standard trucks of the type commonly rated as 3½-ton trucks are best suited for this work. These usually weigh about 5 tons, are rugged, well-built machines, and if given reasonable care, stand up well even under the very adverse conditions often prevailing on construction work. With a two-batch load—4 tons—they are not overloaded, but the weight of the truck and load is so large that rutting may become a serious problem unless dual rear tires (pneumatic) are used, but when equipped with these tires, even these heavy trucks appear to be little if any more destructive of the subgrade than are the ordinary single-batch trucks. Another reason which should lead road contractors to a more general use of the dual rear tire is the fact that trucks so equipped mire down in soft ground much less frequently than trucks equipped with single rear tires. Everyone who has ever operated trucks knows that a large part of his repair bills arises from the astonishing abuse inflicted on stalled trucks by indifferent drivers. Often a careless driver will do a truck more harm in half an hour in trying to get it out of a hole than it would receive in a month of heavy-duty operation on reasonably good roads. There is, therefore, more than the good of the pavement at stake in so equipping heavy trucks that they will not easily mire down.

From the financial standpoint the advantage appears to be with the heavy truck. The initial investment required if heavy trucks are purchased is a good deal higher than where single-batch trucks are used and a better class of drivers must be employed, but the rate of depreciation is less, the number of extra units needed to secure a full material supply at the mixer is less, and delays due to breakdowns are of less frequent occurrence. When computed over a period of years the cost of owning heavy equipment is, for these reasons, less than the ordinary cost of operating single-batch trucks and their use appears to be increasing. It may be added that because of the limited room available on road construction work, short coupled trucks are faster and in general more satisfactory than the long-wheelbase machines, for they take less time as well as less room in turning.

Renting the Whole Fleet.—Some contractors prefer to sublet all of their hauling. This may be done either by agreement with numerous individual truck owners or by agreement with a concern which makes a busines of hauling. As the business of those

who plan the equipment for a job is to create conditions under which a low cost of construction is possible, the question of subletting the hauling must be approached not only from the standpoint of the direct cost of the hauling if done in this way, but from the standpoint of the effect of the arrangement on production at the mixer and also of the effect of low efficiency in the management of production at the mixer, on the cost of hauling.

The fact has been previously developed that if operation is scheduled at 400 batches a day—five-bag basis—about 900 feet of pavement (standard Maricopa section) will be laid and that this is so close to a mile in 6 days that it may be so treated. It would, of course, be equally easy to treat the problem on a six-bag basis in which case the daily production would be well over 1,000 feet, and the number of days required to lay a mile of pavement could be taken with equal accuracy as 5. As there still are more five-bag pavers in use than six-bag pavers, the development will, however, be based on the five-bag batch. The single-batch truck time required in laying a mile of pavement is given in Table V, together with the cost of hauling if the work is sublet, and other pertinent data.

TABLE V

Distance	Average number of trucks required	Days used[a] at 6 days per mile	Cost of[b] hauling at $10 per truck per day	Cost of subletting at 30 cents per batch-mile
First mile	6	36	$360	$ 705
Second mile	11	66	660	1,410
Third mile	16	99	990	2,115
Fourth mile	21	126	1,260	2,820
Fifth mile	26	156	1,560	3,025
Sixth mile	31	186	1,860	4,230
Tenth mile	52	312	3,120	7,050

[a] Not in exact agreement with figures produced by formulae because the assumption of 6 days as required per mile is slightly in error.

[b] For details of composition of this cost see p. 117.

Cost of Rented Trucks High.—It will be apparent from a glance at this table that the cost of hauling when done by subcontract is about double the cost of hauling as it should be handled on a well-operated job, though it should be noted here that, as developed

above, the cost of hauling includes only about a 4 per cent allowance for extra equipment (5.8 days actually required to lay a mile of pavement at rate assumed, as against 6 days used in the table), whereas at least 10 per cent is commonly required. There is, then, nothing to be said in favor of subletting the hauling if both the general paving operation and the hauling are to be efficiently handled.

The Reason for Renting Trucks.—As a matter of fact the practice of subletting the hauling appears to have developed because there has been and indeed still is so much inefficiency in the management of paving work that the investment of large sums in hauling equipment became a very speculative venture. To avoid this speculative element—it is one of the largest in concrete paving work—many contractors pass it on to a hauling subcontractor, avoiding by this practice both a large investment in hauling equipment and the speculation involved in the cost of hauling. The thing often overlooked is the fact that this transaction introduces another speculative element, the rate at which material will be delivered to the mixer under the subcontract, a speculative element often more important that the one so expensively eliminated.

The Basic Cause of High Hauling Costs.—The speculative element in the cost of hauling lies almost entirely in the efficiency of the job management. In the discussions of hauling it has been assumed that the hauling is efficiently handled and that the number of trucks needed for a given haul as given in the tables and in the text above are used. Now the mixer and the truck supply are definitely related services. The mixer cannot produce concrete unless the delivery equipment delivers batches. This is self-evident. It seems not to be as fully appreciated that it is equally true that the material-delivery equipment cannot deliver batches unless the mixer mixes them. In other words, if the management of the balance of the job is faulty, the operation of the trucks simply cannot be efficient. The result is lost time and low production, from which the necessary result is high cost.

Low production on the part of the trucks comes principally from two causes, managerial laxity, which results in cutting down the effective length of the working day, and poor operation while work is being done. The fact that managerial laxity often reduces a 10-hour working day to 8, 7, or even 6 hours has been mentioned before. But hauling costs which are based on 10

hours of work per day cannot be maintained on a job that operates less. Ordinarily the men will be paid for full time because they are on duty for the full time. They burn a little less gas and perhaps wear out tires and machinery a little less rapidly, but other expenses go on just as though the full number of hours were being utilized. The unavoidable result is that production falls in direct proportion to the wastage of working time, while the expense of operation is decreased little if at all. If, then, the hours worked drop to 8, hauling costs tend to rise to 125 per cent of what they should be; if they drop to 7, hauling costs tend to exceed 140 per cent, etc. Now, if the output of the mixer while it is working is low, the same result is had. Trucks enough to maintain a proper rate of output must be furnished. This is not always done but is, in practice, quite generally attempted, except perhaps on the longer hauls. But if for one reason or another, though the truck supply is sufficient to deliver 40 batches an hour, the mixer is taking only 30 batches an hour, the rate of delivery which the trucks can maintain is only 75 per cent of what it should be. There are here the two outstanding causes of high delivery cost: the failure to work the proper number of hours and the failure to maintain the proper output while working. Neither is in the hands of the foreman of trucks if these are owned equipment or in the hands of the subcontractor if the hauling is sublet. The general job management controls the situation. But, as a random illustration, if the job as a whole works only 7 hours a day, seven tenths of the time—and the mixer maintains a rate which is only 70 per cent of standard while work is going on, production at the mixer will fall to less than 50 per cent of standard, with the result that the cost of hauling to it will tend strongly to reach double what it ought to be. As far as the main contractor is concerned, the solution lies in developing better job management rather than in subcontracting this work. Indeed, subcontracting the hauling serves in no way to improve the situation. It merely underwrites the risk that hauling costs may be high.

The Effect of Poor Truck Operation on Mixer Output.—It is not possible to drop the matter here because subcontracting introduces a new element of risk. The mixer cannot run without a material supply. To it the material supply is absolutely vital. But when the subcontractor assumes the risk involved in attempting to deliver materials at a profit to a mixer over the

rate of operation of which he has no control, he commonly gives the main contractor nothing with which to offset the risk he then assumes that the mixer may not be adequately served. The mixer's time is valuable—70 cents a minute, as it has been developed in other places in this book—for when it stops, the rest of the job, in effect, stops too. A very little delay at the mixer due to inadequate material delivery more than offsets any advantage to be had from a good hauling subcontract. As a matter of observed fact, hauling subcontractors often fail to supply an adequate fleet of trucks and, if the fleet is theoretically adequate, often fail so to manage it as to secure the proper volume of delivery. The result is reduced output at the mixer and increased operating cost per yard of pavement laid. Losses from this cause are far too common to deserve extended discussion.

Subletting the Hauling Uniformly Unsatisfactory.—These facts being clear, the blunt statement that the author has yet to see a satisfactory hauling subcontract on a paving job may not seem altogether surprising. Either the contractor or the subcontractor has had just cause to complain. Poor job management makes the hauling subcontractor a heavy loser. Poor management of the hauling equipment or the use of too few trucks produces heavy losses on the main contract. The contractor assumes a wholly unreasonable risk when he places in a subcontractor's hands a service that is of such a nature that carelessness, indifference, or inefficiency on the subcontract can ruin both the organization and the efficiency of his own major operation. It may be added that the subcontractor assumes almost as much risk when he promises to do the hauling, because the possibility of the profitable execution of a contract to deliver batches to a mixer depends entirely on the efficiency with which the mixer he is serving and the general organization around it are operated. The relationship is abnormal and wholly unsound, both in principle and in practice, and should be avoided if it is in any way possible to do so.

In principle, hiring trucks for field stock piling differs widely from hiring them for hauling batches from the material yards to the mixer. The problem of adequate equipment when this system of handling material is used will, therefore, be discussed in the chapter dealing with field stock piling.

CHAPTER VIII

HAULING TO THE MIXER BY TRUCK

To have the proper hauling equipment on the job is one thing. So to operate it as to secure from it the proper accomplishment is quite another matter. Arranging that the proper equipment shall be sent to the job is the duty of those who draw up the construction plans, but its correct operation after it reaches the job is an important part of the work of the superintendent. Indeed, so much is at stake in handling the transportation that it seems appropriate to remark that there is no other phase of concrete pavement construction which deserves as much attention or which is at all likely to repay this attention as liberally.

Delivery to Mixer Must Be Maintained.—In handling the delivery of material the matter of most importance is to secure a rate of delivery at the mixer which is in complete harmony with the mixer's capacity for production, and the matter of next importance is to do this with the correct number of transportation units. The number of trucks to use, full efficiency of operation at proper travel speed naturally being assumed, can be figured for any haul distance from the formulae given in the preceding chapter. This should be done from day to day as the haul distance changes, for a knowledge of the required truck supply is essential to a systematic effort to secure efficiency. A table, or a graph, such as those given in the preceding chapter, may be used if this is deemed more satisfactory. The point is that efficient management must rest on definite knowledge as to what efficient operation requires. It may be added that whether the truck supply is calculated or is reduced to tabular or to graphic form, it is essential that the necessity for a definite, reasonable speed of truck travel and for a definite rate of production at the mixer be recognized. The latter, on well-managed jobs, is provided by the job schedule. The former is set by the characteristics of the trucks in use and the conditions under which they are operating.

Extra Units, Truck Haul versus Industrial Haul.—But while it is possible, by giving the operation of the trucks careful and rigid supervision, to obtain a high degree of operating efficiency, the value of any time lost at the mixer is so much greater than the value of the truck time lost if an extra truck or two are used that it is seldom good policy to reduce the number of trucks to the absolute minimum determined on the basis of perfect operating efficiency. For this reason, the careful superintendent will, in practice, protect the supply of material at the mixer even though the efficiency with which his transportation is operated appears thereby to be somewhat reduced. Indeed the fact that this can be done is one of the outstanding features of truck delivery. There is here rather a wide difference between trucks and industrial railway. When the latter is used, there is little advantage to be had from adding an extra train or two in order thereby to avoid the effect of accidents, poor train management, etc., for, in its general effect, a poorly worked out switching practice at the mixer or a derailment along the line stops the whole delivery operation just about as effectively as stopping the mixer stops production. It has, in short, never been possible sensibly to avoid the consequence of poor train management or of accidents to trains by adding extra trains. But because trucks act independently of each other, it is possible to avoid many of the consequences of accidents and accidental delays merely by using a few extra trucks. On hauls up to 2 miles, single-batch trucks being in use, this should normally require not more than one truck in addition to the number required under perfect operation. At from 2 to 4 or 5 miles, two extra trucks may be required. The margin need not be large, but ordinarily it is good practice to provide some margin for a few unexpected and unavoidable delays will occur even under the best management.

Varying Truck Supply with the Haul.—As the haul varies, the number of trucks used must be varied if there is to be any approach to efficient operation. One rather frequently sees jobs where the number of trucks used in hauling batches is maintained at a constant figure. This is a highly inefficient practice. Under this practice when the haul is long, the supply of material at the mixer is inadequate, and when the haul is short, the cost of hauling mounts because the production per truck is low. The only proper way to handle the hauling problem is to vary the number

of trucks used according to the length of the haul, usually adding one or two trucks to avoid the effect of short delays.

Theoretical Aspects of the Use of Extra Trucks.—The foregoing presents this matter from what may be termed the practical standpoint. From the theoretical standpoint the problem is one of equating the value of mixer time against the value of the time of the transportation units in use. It must be clearly appreciated as the very essence of correct management, that, whenever the mixer loses a minute, the whole job has lost a minute. It is totally impossible to set an independent rate of operation for the material delivery and then to maintain this rate. The rate at which this as well as other operations incident to laying a pavement must be performed is, of absolute necessity, set by the mixer. Moreover, men are paid by the hour or the day, whether they do much or little, and equipment is worn out on the job at a pretty uniform rate without much regard to whether it produces anything or not. It will also be clear to those who are at all familiar with this work that the personnel commonly is maintained on a full-production basis without regard to the rate of production. In other words, the size of the crew is fixed by the equipment used and the methods followed rather than by the rate of production. The cost of today's run (the value of materials, of course, excluded) is, then, in no way affected by the amount of today's run whether that be 300 or 1,000 feet. (This would not hold if the low production was caused by a reduction in the number of hours the crew was on the job and so the number of hours for which labor is paid. It is presumed here that the low production is due to a low rate of production.) It is not possible in a book of this sort to go into the details of cost, but for purposes of illustration, reference will again be made to the fact that, in a very general way, the daily operating expense on a concrete paving job (10-hour-day basis) is not far from $400. There are 600 minutes in the working day; so it naturally follows that a minute lost by the mixer is worth about 66⅔ cents, or for ready calculation, say 70 cents. This figure will do well enough for purposes of illustration, but the superintendent or the contractor who is checking up his own operations should determine it more exactly on the basis of his own records.

The Cost of Operating Single-batch Trucks.—Now the operation of a single-batch truck will generate a daily cost somewhat as follows:

Driver	$ 3.50
Gas and oil	3.00
Tires	1.00
Repairs	1.50
Interest and depreciation	1.00
Total	$10.00

This calculation, like the previous one, is subject to considerable variation due to regional differences in the price of labor, gas, oil, etc. and should be recast by a contractor on the basis of his own records when it is to be used in the control of his work. On the other hand, both figures are, in a general way, representative of the conditions commonly prevailing; so they offer a fair basis for a comparison of the value of any time lost by the mixer and the value of time lost by the transportation units. The relative value of the time of other types of trucks may, of course, be calculated in this same way.

Determining the Number of Extra Trucks.—If mixer time is worth 70 cents a minute, the loss by the mixer of 15 minutes is as important to the contractor as the loss of a whole day of single-batch truck time, or he can better afford to have two extra single-batch trucks at work on the job than to drop ½ hour of time at the mixer. A point to be noted here is that on most jobs any loss of time at the mixer which is caused by a shortage in transportation will occur in small intervals—a minute here and half a minute there. As a result the amount of time lost in this way is quite generally underestimated. The only satisfactory way to determine the amount of such losses as this with accuracy is through stop-watch readings extending over a period of a number of hours.

If, now, the purpose is to maintain production at some definite rate, as 45 batches an hour, which is one batch every 80 seconds, it is worth while to supply an extra single-batch truck, whenever operating conditions are such that during the day it can increase production by as little as 12 batches! The relatively small increase in production which will justify the use of an extra truck or two is, therefore, apparent. Whether such units should be rented temporarily, supplied from stock, or purchased will depend on the general considerations under which the job is operating.

A Special Method of Working Extra Trucks.—While it is the more common practice among contractors to work extra trans-

portation units as part of the regular fleet, some adopt the rather interesting practice of loading out such units in the morning and stationing them at the mixer, where they remain until a gap in the material supply requires the utilization of the material they carry. They are then reloaded and returned to the mixer to wait until another failure in the delivery occurs. This method of operation is particularly adapted to use where the hauling is done under a subcontract which is reasonably satisfactory but not altogether so, for it enables the main contractor to protect his mixer output without unfairly encroaching on the subcontract for hauling and accomplishes this result at a relatively low cost to him.

Things That Affect the Operating Efficiency of the Trucks.—The purpose in the above discussion has been to show that keeping up production at the mixer is so important that it is sound policy to protect production at the mixer even if, to do this, some transportation in excess of theoretical requirements is used. But while it is essential that the supply of material at the mixer be kept up, it is also essential that this be done on an efficient basis. This, in turn, requires that the job be constantly searched for factors adversely affecting the operating efficiency of the trucks. Graph *C* of Fig. 39 illustrates how low the efficiency of operation may drop when this angle of the work is not subjected to constant scrutiny. Low efficiency, such as that shown in Graph *C* of this figure, results from all sorts of causes. One of the most common is the interest which drivers take in the repair of minor defects on their trucks as soon as it is learned that this excuse will make it possible for them to avoid an honest day's work. Positive "hiding out" along the route is uncommon, though not unknown, but the number of little things that can be done to delay matters, a few seconds here, a few there, is surprising. None of these, however, is as effective in reducing efficiency as is the driver who deliberately reduces his speed, thereby causing trucks to pile up behind him. If high efficiency is to be secured in the operation of trucks, it is imperative that drivers be taught to drive the course in the proper time.

Slow Driving.—On most jobs there are four points where the trucks stop: (1) the aggregate bins, (2) the cement sheds, (3) the turntable, and (4) the mixer. Ordinarily from ¼ to 1 minute is required in servicing the truck at any of these four points. If, then, by reason of the slow driving of one truck, the pace has been so reduced that four or five trucks arrive at the loading

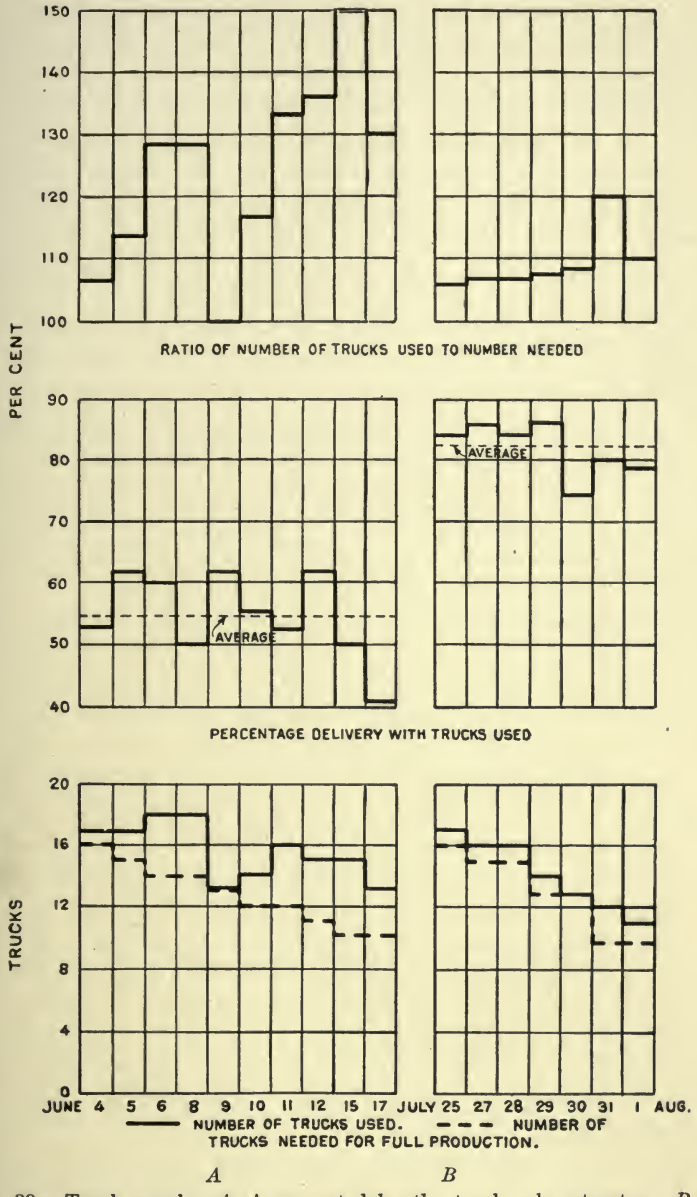


FIG. 39.—Truck supply: *A*. As operated by the truck subcontractor. *B*. As operated under scientific management.

plant in a string, all but the first will be delayed in loading. Take a specific example, involving a 10-minute return trip, and operation at the mixer at the rate of 40 batches an hour, or one batch every 1½ minutes. Suppose the first truck is delayed a minute in its "get-away" from the mixer and is then driven at a rate that will require 14 minutes to make the return trip. When it reaches the cement shed, it will be 5 minutes behind schedule. The next truck leaves the mixer promptly, ½ minute after the first, trailing it in. It is, then, 3½ minutes late in arriving, but because the cement shed can load only one truck a minute, it waits there 1 minute to be loaded and leaves 4½ minutes late. The third truck, catching the first two, trails in with them, arriving 2 minutes late and is held 2 minutes waiting to be loaded, making it 4 minutes late out of the cement shed. It will be clear without extending the illustration that, as stops occur at the batcher, at the cement shed, at the turntable, and at the mixer, the trucks must be run at a uniform rate and kept at such a distance apart that they will not lose time waiting for service at these points, if high efficiency is to be obtained.

Fast Driving.—On the other hand, many superintendents seem to feel that the fast driver does no harm. The contrary is outstandingly the case. Of course, a fast driver often does serious damage to his truck but wholly aside from this, he is a nuisance on the job and should be eliminated just about as vigorously as the chronically slow driver, for, while he may get a few more loads than the other drivers, this really is done at their expense and with no advantage to the job. Thus, if he makes what should have been a 10-minute trip in 8 minutes, the driver who has been "nosed out" of position is forced to wait for service at the cement house, and leaves there little if any ahead of the time when the fast driver would have left had he kept his proper place in the line. The fast driver causes much ill feeling among the men and not infrequently serves as a cover for the laxity of other drivers, for if fast driving is permitted, the position of the various trucks changes enough during the day so that a good deal of shirking may escape unnoticed.

Maintaining Proper Speed.—The proper method of handling trucks is to determine a rate of driving speed that is in harmony with the characteristics of the trucks and the condition of the roads over which they must operate. Commonly this will be somewhat less when the trucks are loaded than when they are

light. When this speed is established, it must be maintained. To this end, trucks should be equipped with speedometers and the men trained to watch them. Fast driving and slow driving should be alike forbidden, and any failure to comply with this requirement should result in summary dismissal.

Where trucks tend to run in bunches, it usually will be found that once the matter is thoroughly explained to the drivers, most of them will cooperate willingly in eliminating the trouble, but a few will consider the matter of no consequence. These must be eliminated. It is well worth while to keep a checker at the cement shed to record the loads hauled by each truck and to note the time out and the time back in such a way that the drivers can learn how close to schedule they are driving. Most drivers will cooperate willingly if they have this assistance and, with other parts of the job running smoothly, can and will handle the material delivery with the accuracy of a well-administered train schedule. The point is that it is only a little less difficult to operate material trucks between the material yard and the mixer on an efficient schedule without supervising assistance and without speed indicators than it would be to operate trains without a dispatcher. The checker at the material plant should act as a dispatcher, and if he has the right personality, he can assist materially in keeping the trucks properly spaced and their operation generally on a basis of high efficiency.

The Time Clock as a Speed Control.—A standard time clock can be used to advantage on this work. Where used, it should be set ahead as many minutes as are required for the round trip. Then, by stamping each driver's card as he leaves a fixed point in the circuit—the batcher plant is a satisfactory point—the driver is automatically provided with a printed record showing the exact hour and minute he should be at this point in the yard again. Moreover, as the card is turned in for restamping, the checker can note actual time and gain or lag, so that the driver as well as the superintendent may know whether he is driving correctly or not, and if not, how much he is habitually off schedule. A system of this sort will show who are the poor drivers within a surprisingly short time.

The Effect of the Roadway on Driving Speed.—Beside the careful control of driving practices, the care of the roadway over which the hauling must be done is an important factor in efficient truck operation. Slow operating speed not infrequently results

from the fact that the road between the batcher plant and the mixer is in such condition that a higher speed is out of the question. It is a matter of observed fact that contractors pay too little attention to the condition of the roads over which their trucks are operated. These commonly are earth roads, and heavy hauling naturally causes ruts and chuck holes. High speed, even a moderate speed, can be safely maintained only when the roads are reasonably smooth. Therefore, to obtain full efficiency from the trucks available requires that the roads be kept in the best possible condition, and this in turn requires that the provisions for road maintenance be at least as complete as any state or municipality would provide in caring for the more important roads of the same type under its jurisdiction.

The Financial Aspects of Poor Hauling Conditions.—Perhaps the clearest way of presenting the financial aspects of this matter is to refer again to the fact that on a standard (five- or six-bag) concrete paving operation the daily payroll is likely to be in the neighborhood of $200 and the daily depreciation charge at least half as much. Operating costs, overhead, and miscellaneous costs commonly are rather heavier than depreciation charges. Mixer time, therefore, costs the contractor perhaps 70 cents a minute. If, then, the condition of the roads is allowed to become so bad that full efficiency cannot be had from the trucks, and no extra trucks are available to make up this deficiency, there is, in addition to the direct increase in the cost of hauling, the indirect cost which results from slowing down the job as a whole, often the more important loss of the two.

Take, as an illustration, a job where the regular rate of output is 40 batches an hour. If 20 single-batch trucks are available and should, with full efficiency, deliver 40 batches an hour, but because of road conditions can only deliver 32 batches an hour, it is apparent that the cost of hauling has been increased 25 per cent. But in addition to this, the mixer output has been reduced from 83.33 per cent to 66.66 per cent of full production, a net loss of 16.67 per cent of the day, or 100 minutes, which, at the rate of 70 cents a minute, costs the contractor about $70 for every day during which these conditions persist.

Maintaining Roads Used for Hauling.—Losses of this order are by no means uncommon though perhaps not the rule. Such as do occur, however, are apt to be large enough to warrant a contractor in keeping a light grader and team or tractor at work

whenever it is possible to use it to any advantage. Nor should the fact that the hauling has been sublet constitute in his mind an argument against providing this equipment and doing this work, for, as is clearly shown above, his indirect loss from slow delivery of material may easily exceed the subcontractor's direct loss from low truck efficiency and high repair costs.

The operation of a good road maintainer would hardly cost the contractor more than from $6 to $8 a day, and ordinarily the whole time of this outfit would not be required in maintaining the roads. Therefore, whenever slow delivery of materials due to the condition of the roads causes loss of time at the mixer which exceeds from 12 to 16 minutes a day, giving attention to the condition of the roads is likely to prove profitable even though all hauling equipment is owned by a subcontractor. Where the delivery equipment is owned by the contractor, the reduced depreciation and repair costs which result from operation over smooth roads will, of itself, justify the cost of road maintenance and should dictate that it receive careful attention.

The Effect of Yard Equipment on the Hauling Time.—The time consumed by a truck in hauling a batch is made up of the time required to drive from the material yard to the mixer and back and the time required in loading the truck at the yard and unloading it at the mixer. The effect of poor road conditions on driving speed has been noted. It may be added that whatever reduces the speed at which the hauling is done reduces the output which can be had from a truck. Often, however, it appears not to be so fully appreciated that extending the time required in loading or in unloading the trucks has the same effect. In practice, it has been found that where the yard design is good, the equipment there good, and work about the mixer well done, single-batch trucks can be serviced in about 4 minutes while two-batch trucks require about 6 minutes. The operations performed are as follows:

	One-batch trucks	Two-batch trucks
At material yard:		
Load aggregate	15	45
Load cement	30	60
Driving through yard	60	60
At mixer:		
Handling cement[1]		
Turntable	25	30
Extra time backing to mixer	45	45
Dumping load	15	70
Delays	50	50
Total	240	360

[1] When cement is carried on batch, bags for first batch should be emptied while truck is being turned and backing to mixer. When cement bags are emptied into skip, the unloading time of two-batch and larger trucks is apt to be increased by about the time it takes to handle the cement for the number of batches carried less one.

The necessity for better methods in handling cement and for a good yard layout, indeed for care in all phases of this work, can perhaps be brought out in no better way then by calling attention to the fact that if production at the mixer is at the rate of 45 batches an hour, the use of a poor plant layout, of obsolete or improperly designed equipment, or of improper practices, anything in short which adds 1¼ minutes to the time required in servicing a single-batch truck, requires the use of an additional truck in order to maintain production. It will be clear from this that careful plant layout and the selection of proper methods and proper equipment for the yard are essential if the trucks are to operate at high efficiency.

Dump Bodies.—What has been said of the relation of the material-yard layout to the efficient operation of the trucks may also be said of the dump bodies used on the trucks themselves. Often, particularly where single-batch trucks are used, these are homemade wooden affairs of the crudest design. Such bodies have a double disadvantage in that they are likely to be so carelessly put together that more or less material, particularly sand, spills through the cracks between the boards of which they are composed, and that they are so poorly balanced that they are difficult to dump. The first condition wastes material and by so doing tends to reduce the yield. Poorly balanced truck bodies

often cause the use of an extra truck dumper at the mixer (Fig. 40). In occasional instances dump bodies of such poor design are used that three or four men may have to be called on to help dump the load. Finally, the tendency of all wooden bodies is to dump slowly. The use of rough lumber accentuates this tendency and a poor design—too long a body for its height above the ground is a good illustration—may so retard the rate of discharge that it cannot be completed within the time available. Cases as bad as this are rare, but single-batch trucks with homemade bodies have been found in use which took an average of as much as 2 minutes to discharge a batch. In cases as bad as this, indeed

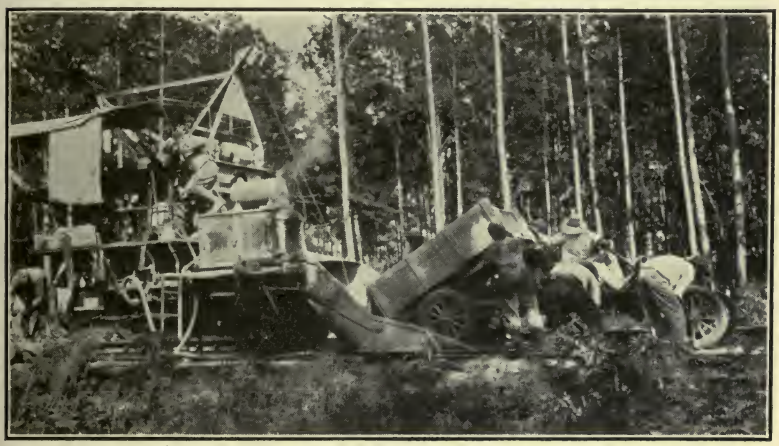


FIG. 40.—A poorly designed wooden dump body. Note two men dumping load.

in any case where the dumping time exceeds about 50 seconds, the mixer is held up. It commonly takes about 10 seconds to raise the skip. The skip is held in a vertical position to complete the discharge for from 5 to 10 seconds and it ordinarily takes 2 or 3 seconds to lower it. As a general thing the total time required for these operations is a little over 20 seconds. Of course, the skip is not available for a new batch while they are being performed. Some 5 seconds are required to back the truck into the skip after it is in position to receive the next charge. Often a longer time than this is used. There are, then, rather less than 50 seconds available in which to dump the load before the skip should be raised again; so any sort of a dump body which is so clumsy that more than this amount of time is required in dump-

ing it not only tends to reduce the number of loads which can be hauled by the truck, but also delays the mixer. Any truck which regularly does this is too expensive to have on the job.

The Proper Dump Body for the Single-batch Truck.—The desirable body for single-batch trucks used on concrete paving work is a steel body about 6 feet long so carried that when the hooks which hold it in position are released, it will dump with little or no assistance from the dumpman.

Truck bodies should not be carried too high off the ground, as this tends to rack the truck. Moreover, the general result where this is done is the loss of rather too much cement in dumping. Long bodies are objectionable, as they do not permit of the

FIG. 41.—Single-batch truck equipped with a good wooden body, short but deep.

high dumping angle required for a quick dump unless they are carried too high above the ground. Mechanically operated dump bodies for single-batch trucks should be avoided. Most types have proved slow in actual operation. A single-batch truck equipped with a well-designed dump body and well trimmed can be dumped and gotten out of the way in from 15 to 20 seconds. Moreover, only one dumpman is needed to assist in dumping such a truck. There is therefore nothing to be gained by using any of the commoner mechanical dumping systems, and their use is not to be recommended.

Trimming the Load.—Some care is required in placing the load if these, or for that matter any, of the common single-batch dump bodies are used. To secure an easy dump it is good policy to load the gravel or stone first, then the sand, and finally the cement.

As this is dumped by hand, it can readily be put far enough back so that the load is heavy at the rear end. Most truck bodies are hung loose enough so that well-trained cement handlers can tell

FIG. 42.—Single-batch trucks with steel bodies. Forms in place and a good subgrade.

rather easily whether the load is properly trimmed. They should be cautioned on this point and their work watched to see that it is

FIG. 43.—A high-grade, properly equipped, two-batch truck.

properly done in this particular, as a good deal of time can be lost at the mixer by the improper trimming of even the best dump bodies.

Desirable Bodies of a Two-batch Truck.—Two-batch trucks for this work are always equipped with steel bodies and, in the nature of the case, require the use of some mechanical means of dumping the load, for it would be almost impossible to handle a two-batch load on any other basis. Two things should be observed in regard to the dumping device. First, it should be capable of dumping the first load well within the time available. This, as was shown above, limits the time to something under 50 seconds, as the dump must be completed and the truck moved out of the skip well within that time or the mixer will be delayed. Dumping devices have been improved a good deal within the past few years, but there still are trucks in use which cannot dump the first batch within that time.

FIG. 44.—A fast-dumping, single-batch body. Note apparent loss of cement in dumping. The actual loss is trifling though there is the appearance of a considerable loss.

The second point to be watched is whether the dumping mechanism can be jammed or wrenched out of line if it is required to function when one of the rear wheels of the truck is in a deep rut or when the truck is otherwise in an awkward position. In the past a good many dumping mechanisms have shown inadequacy under such conditions, and while such conditions are not very common on paving jobs, heavy trucks purchased principally for use on paving work are often also used on other sorts of construction work where, particularly on grading work, it will be found that a dumping mechanism that will not function freely and properly under the most adverse conditions will cause a great deal of annoyance and expense. It is, in short, as necessary to look to

the ability of the dump bodies to function regularly within the time available to them as it is to look to the ability of any other part of the equipment to function regularly and properly within the time allotted to it. If this is done, a good many of the cheap bodies may have to be replaced by better ones. High efficiency can be obtained, however, only when all parts of the job are capable of high efficiency. The dump body on a truck may seem to be an unlikely place to look for delays. Nevertheless, delays are to be found there on far too many jobs, and the remedy is, as in other equipment difficulties, the use of well-designed and properly constructed equipment made by reliable manufacturers who make it their business to build high-grade equipment.

CHAPTER IX

FIELD STOCK PILING

Hauling the aggregates to storage piles along the road, from which points they are later moved to the mixer, was devised as an advantageous means of bringing together, at appropriate sites along the line of construction, sand and coarse aggregate necessarily obtained at different points. Generally it is the best method to use under such conditions but, unless the maximum haul is unusually long, it is not a sound method of operation when a common point of delivery for the coarse and the fine aggregate can be had, for it necessarily involves rehandling the aggregates, a considerable amount of extra working time for the trucks, and heavier stock-pile losses than are involved in direct haul from the material yard to the mixer. On the other hand, this method offers some advantage over the direct delivery of aggregate in measured batches from such causes as that the efficient handling of equipment assigned on stock piling is not prejudiced by conditions at the mixer, that no special equipment of the dump bodies used on such trucks is necessary, and that such considerations as uniformity in length of wheel base, capacity, speed, etc.—considerations which sometimes affect the usefulness of available trucks in delivering measured batches—are not of any importance in this work.

Building Stock Piles.—No extended comment on the practices used in connection with the delivery of material to stock piles is needed. Where field stock piling is done, the sand and the coarse aggregate are hauled to selected sites along the route to be paved and there piled. Generally an effort is made to select sites on the tops of knolls or small hills so that the drainage away from the piles will be good. The selection of good sites is important, for even under the best conditions the piles so blanket the ground under them that evaporation is slow, and as a result it tends to hold enough moisture to keep it soft long after uncovered ground has become quite dry. The result of this is that a good deal of aggregate has to be left to support the trucks in their operations around the stock piles (Fig. 46).

In making the piles the trucks dump a layer on the ground over the area to be used, this layer being leveled off on top generally

FIG. 45.—A pair of field stock piles with loaders in position.

by men kept at the stock piles for that purpose. When the first layer is finished, a ramp is formed at one end, plank commonly

FIG. 46.—Typical condition around stock pile as material is taken away.

being laid on the ramp and as needed over the top of the pile (Fig. 47), and another layer is dumped. It is not good policy to work out a ramp to the desired height and then end dump the

coarse aggregate to the full height of the stock pile as sometimes is done in making earth fills, for too much segregation of sizes results, though there is no reasonable objection to handling sand in this way.

Stock Piling Can Be Sublet.—It is the general practice to place the stock piles well in advance of paving operations. Therefore, this work need not enter into the superintendent's day-to-day production plan. In this respect it is an outstanding exception

FIG. 46*a*.—The ground under a large stock pile often is so wet that deep ruts are formed by the trucks. Much material is lost in this way.

FIG. 47.—Building a field stock pile. Note good mats in the foreground.

to the general rule that, in paving work, all operations must be conducted at a uniform rate which is established by the mixer, for this work can be done at a totally different rate and, if need be, at a different time. All that is required is that the stock piling be kept far enough ahead of paving so that the two operations shall not conflict. On this account no such objection as lies against subletting the hauling of batches from the material yard to the mixer can reasonably be made to subletting this work. Indeed it is just the type of work which can be profitably handled by a subcontractor, that is, work so unrelated to the conduct of

the general operation that the day-to-day efficiency with which it is handled does not affect work on the main contract and that the day-to-day efficiency with which the main contract is handled does not affect it.

Equipment Required.—For operation under this system of handling aggregate, the ordinary hauling equipment is a combination of light trucks and heavy trucks, the latter being used in delivering materials to the stock piles and the former in delivering them from the stock piles to the mixer. In calculating the number of trucks required for stock piling the aggregate, a suffi-

FIG. 48.—A large truck delivering material at the stone stock pile.

ciently accurate determination may ordinarily be had by first computing the ton-miles of haul involved in the stock-piling program and, where the haul is 5 miles or less, dividing this by 4.8 times the average load to be hauled in tons, which will give the number of truck-hours involved. If the haul is over 5 miles, the factor 5.7 should be used instead of the factor 4.8. The number of truck-hours divided by the number of hours per day during which the trucks will operate will give the number of truck-days, which, when divided by the number of days that may reasonably be allowed for the work, will give the number of trucks required.

A Calculation of the Trucks Required for Stock Piling.—As an illustration, let it be assumed that crushed rock and sand are to be stock piled, the sand being delivered at the railway siding 1 mile north of the road and the stone at a quarry 1 mile south of the road. Stock piles are desired at points 1, 2, 3, 4, and 5 miles from the points of origin of these materials, the piles to net

4,000 tons after allowing a 5 per cent loss of material in the bottom of each stock pile. The hauling involved is then as follows:

	Ton-miles	
To stock pile 1	4,200	
To stock pile 2	8,400	
To stock pile 3	12,600	
To stock pile 4	16,800	
To stock pile 5	21,000	
Total	63,000	ton-miles of haul involved

If the average load to be carried is 5 tons, the ton-miles per hour of truck time is 5 times 4.8, or 24.0, and the total number of truck-hours which are involved is 63,000 ÷ 24, or 2,625 truck-hours. If 10 hours' work will be done per day, the stock piling will, then, require 262 truck-days, and if this work must be done within 35 days, eight trucks must be used. This is merely illustrative of the method to use. Each job will, of course, present new conditions and will require a separate calculation.

A More Exact Basis of Calculation.—In practice, an element of error in the above method of calculation is introduced by the fact that no fractional trips are made. As a result, particularly on long haul, quite a little time may be lost if the trucks never run longer than the nominal working day. The formula for the round-trip time T which ought to be expected of the ordinary heavy-duty trucks used on this work is

$$T = 4 + 10d$$

By the use of this formula a calculation which is more exact than the above rough calculation can be made, but little would be gained by so doing, as the common practices governing this work make such important elements as the number of hours worked and the load carried, so variable that the possibility of obtaining better results from a more exact basis of calculation is remote. The method of calculation which is recommended is based on an ordinary degree of operating efficiency. If the efficiency with which it is likely to be done is above normal, a higher factor can be used. Time lost in loading, unloading, manipulation, waits, etc., however, generally amounts to about 20 per cent on hauls under 5 miles, and the factor 4.8 appearing above is based on this percentage of lost time. If on the other hand the efficiency of operation is low, provision for the larger amount of wasted

time must be made by adding to the number of trucks which the above method of calculation shows to be the number of trucks of this type with which the work ordinarily can be performed.

Relative Efficiency in Stock Piling.—It may be remarked that low efficiency on this work is not as common as it is in other phases of paving work. This, as was suggested above, is due to the fact that hauling to the stock piles is an independent operation. The low efficiency in the operation of batch trucks which is so often found on concrete paving work is in large part due to the fact that high efficiency can be obtained only where there is good coordination throughout the rest of the work. If the mixer, as a random illustration, breaks down, the amount of material delivered by the batch trucks is adversely affected. If the subgrading gets behind, this slows down the mixer which, in turn, slows down the trucks. On poorly managed jobs, there are any number of delays of this sort, not originating in the operation of the trucks themselves, which affect their output. Hauling to stock piles is wholly independent of other operations except the rate at which material is delivered to the points from which the hauling is done. It really is rather a simple matter so to coordinate the batch-truck supply and the mixer output that high efficiency in truck operation is possible, but the fact that it so often is not done, whereas a satisfactory efficiency can be maintained in stock piling without regard to efficiency in other parts of the work, tends to create the impression that the stock-piling method is basically the more efficient of the two. Indeed, costs tending to prove this superior efficiency are occasionally seen in the technical press. If inefficiency in the management of production on concrete paving work is accepted as unavoidable, the natural and reasonable deduction would be that as stock piling can be efficiently handled no matter how inefficiently the rest of the job is managed, its adoption should reduce hauling costs. If, however, it is assumed—and that is the assumption of this book—that high efficiency can be developed in all parts of a concrete paving operation, the advantage claimed under the more usual assumption appears wholly unwarranted.

Heavy Work in Reverse Gear Required.—While the standard 3½- and 5-ton dump-body trucks are usually selected for this work, other types are occasionally seen in use. It may be remarked, however, that in order to perform satisfactorily trucks assigned on stock piling should have a low reverse speed and

should be properly designed for backing up heavy grades under considerable overload (Fig. 49). The ramps leading onto a large stock pile often are on grades as high as from 15 to 20 per cent; so unless a truck has been designed for heavy service in reverse gear, a good deal of trouble may develop if it is put onto this sort of work.

Ramp Pitch Cannot Be Reduced.—A remedy which suggests itself is the construction of longer ramps carrying lighter grades. This, however, is not altogether practical, both because of the

FIG. 49.—Stock piling requires heavy uphill pulling in reverse gear.

space involved and because of the loss of material which would result. To get onto a stock pile 15 to 20 feet high takes a good deal of room at best and involves a good deal of loss of material. It is better to select trucks that will back up a steep grade, for the best trucks will do this readily enough, than to select poor trucks and then pay heavily in material losses for having them.

Truck Supply When Mixer Must Be Started at Once.—Sometimes the number of heavy trucks which must be used is affected by the point at which work is to begin, or the time mixing must start. Thus, if, as is commonly the case, it is deemed advisable to begin work at the farther end of a project, continuing the illustration used above, the trucks engaged in stock piling must be given a proper time within which to place the stock piles there before mixing starts. In this case, the eight trucks the original calculation showed to be needed would require 10 days in order to place the stock piles at the far end of the job (2,100 ÷

(5.7 × 5 × 10 × 8), or 10). Moreover, 8 days would be required to place the second group of stock piles. This would be about 4 days longer than would be required under a high rate of efficiency to mix and place the first mile of pavement and 2 days longer than required on the second mile. To keep the stock piling ahead of the mixer 6 additional days would, then, be required, if stock piling were kept out of the way of the general job operation, a condition that is highly desirable though not absolutely necessary. But if this time was not available and the work could not be arranged so that the mixer could begin at the other end of the project and so give the heavy trucks the initial advantage of a short haul, because, for instance, this would interfere with stock piling on the rest of the project or add too much to the haul, or for some other equally valid reason, the solution would lie in the temporary employment of extra hauling units or in the overtime use of the units which would be normally employed. Double-shift work sometimes is resorted to. One job has been observed where such as are needed of a fleet of 3½-ton trucks are effectively used during the day as batch trucks to haul from the stock piles to the mixer, while at night, with a fresh crew of drivers, the whole fleet worked on stock piling. The arrangement has been very satisfactory and has materially reduced the required investment in trucks.

Equipment for Hauling from Stock Piles to the Mixer.—The equipment needed for carrying batches from the stock piles to the mixer is governed by the distance by which the stock piles are separated. Commonly these are placed a mile or so apart. To place them closer than this sharply increases the loss of material under the stock piles, though it decreases the number of batch trucks required. To place the stock piles farther apart decreases the losses of material but increases the number of batch trucks required.

The formula for calculating trip time when single-batch trucks are used on this work is

$$T = 6 + 8d$$

Two-batch trucks are seldom used on this work but, where observed, have shown a travel speed yielding a formula

$$T = 8 + 8d$$

If the stock piles are placed 1 mile apart, general conditions and driving speed being normal, 12 single-batch trucks, the type commonly used for this work, are required, and if the separation

is 2 miles, 18 single-batch trucks should be available. These figures assume efficient operation but allow for practically no surplus hauling equipment when the haul reaches a maximum. The general use of formulae of this kind was developed in Chap. VII.

The Spacing of the Stock Piles.—To determine the most economical spacing of stock piles it is only necessary to equate the difference in stock-pile losses under the various spacings which are being considered against the increased carrying charges generated by the additional trucks used as the distance between the stock piles is increased. If material losses were constant, this would be easy enough to do, but ground conditions differ widely, a condition which materially affects the amount of aggregate lost. Increasing the distance between stock piles has no effect of much consequence on the work to be done in hauling the materials, that is, on the number of ton-miles of hauling to be done. Its principal effect is to alter the relation between the work to be done by the heavy trucks and by the light trucks. As far as the truck side of the problem is concerned, as between ½-mile spacing, for instance, and a 2-mile spacing of stock piles, it resolves itself, then, into the cost of standby equipment as compared with the cost of the material lost and the haul on this material. With ½-mile spacing between stock piles the number of trucks needed to keep the mixer supplied will vary—efficient management assumed—from 6 to 9, an average of 7½ trucks, and if 9 are carried, the average standby truck time will amount to the full time of 1½ trucks. If stock piles are 2 miles apart, the number of trucks needed to supply the mixer will vary from 6 to 18, or an average of 12 trucks, and if 18 are carried, the average standby truck time will be 6 trucks. The cost of standby truck time, as has been previously shown, would properly include interest on the investment, the cost of getting the truck onto the job, etc., which would be rather liberally calculated for a single-batch truck as follows:

Interest	$ 50
Dead storage	50
Cost of getting to and from job	100
Annual standby cost	$200

The cost of standby equipment when stock piles are ½ mile apart is then perhaps $300, while when the stock piles are placed

2 miles apart, it is about $1,200; so the cost of the greater separation of the stock piles, due to the larger average standby truck time thereby involved, is not more than $900 during a full working season. It is this figure against which the value of material lost by increasing the number of stock piles should be equated.

The Nature and Amount of Stock-pile Losses.—In stock piling it is generally required that the piles shall be constructed in layers, and as it is easier to build low piles covering a large area than to build high piles covering a small area, there is rather a noticeable tendency to make the area of the piles more nearly constant than the height. But the material losses incident to stock piling are a function of the area rather than of the height. It is difficult to reduce these losses much below an amount equal to the bottom 6 inches of the stock pile. For stock piles 10 feet high, this is a loss of something more than 5 per cent of the material, but for stock piles only 5 feet high it represents more than 10 per cent of the material stock piled. The tendency is to exceed these limits. A stock pile on good ground, studied in 1926, showed a net loss of 11 per cent. This pile was over 20 feet high.

These losses are due in no small degree to the necessity of working around the stock piles during wet weather. Moreover, the ground does not dry out very perfectly under a stock pile; so it often happens that as the piles are worked back, ground is uncovered which is so soft that the trucks rut it badly and even in occasional instances mire down so that they have to be pulled out. The ruts thus formed collect water during wet weather, which tends to aggravate the difficulty of handling the trucks as well as to increase material losses, for using the trucks around the material piles when such conditions prevail mixes much material with the underlying mud and so renders it unfit for concrete work.

If stock piles are placed 2 miles apart, the general practice would be to make high piles, while if they are only ½ mile apart the tendency, in general, would be to make low piles. There is not enough uniformity of practice in regard to this matter to justify positive statements, but in a general way, close stock piling has the effect of increasing stock-pile losses by perhaps as much as 5 per cent of the gross amount of material stock piled. This would be, generally, some 200 tons per mile of pave-

ment. The value of material necessarily varies from job to job but, taking a random case where materials are worth $2.50 a ton f.o.b. railroad station, handling costs are 10 cents a ton, and hauling is 20 cents a ton-mile, the value of the extra material lost would average a little over $3 a ton if the maximum haul is 5 miles. The extra stock-piling losses due to close piling would, then, average $600 or more a mile, which, for a season's work of, say, 12 miles, would amount to the rather imposing figure of more than $7,200. This is the figure against which the cost of standby truck time should be equated.

FIG. 50.—Working around a field stock pile as the trucks must to reach the loaders causes heavy losses of material. Losses around this pile amounted to 11 per cent. The stock pile was over 20 feet high.

The Basic Relation between Batch Hauling and Stock Piling.—It may be noted that a continuation of this line of reasoning shows the utter fallacy of stock piling as compared with direct haul from the material yard, if the maximum distance from the material yard to the mixer can be kept within such bounds as to make good management of the batch trucks possible and keep standby costs within reason. The following calculations (see Fig. 52) bring out the mathematical aspects of the case, the deductions being predicated on the fact that where materials are sent out in

batches from a well-designed material yard, the stock-pile losses at the yard will be no greater than average stock-pile losses under each set of field stock piles. Actually the losses in a material yard tend to be less than the field losses on piles of the same size, because the trucks necessarily work over the material left around field stock piles, which, as a result, becomes so dirty that it cannot be used, whereas material left in the same way in a yard stock pile is not disturbed and so can be more completely recovered.

Time Losses Involved.—Now, to proceed with the mathematical aspects of this matter, if material is stock piled, as at A, the truck time involved in hauling it (the use of single-batch trucks for all operations being assumed for the sake of simplicity) is

$$T = 4 + 8d_1$$

and the time involved in hauling from the stock pile to the mixer is

$$T = 6 + 8d_2$$

The total truck time involved is then

$$T = 10 + 8(d_1 + d_2)$$

But $$d_1 + d_2 = d$$

So $$T = 10 + 8d$$

Now for direct haul the formula is

$$T = 4 + 8d$$

There is, then, a direct loss of 6 minutes of truck time per batch of material hauled when field stock piling is done.

Material Losses Involved.—Then there is the loss of material at the bottom of all stock piles, which will be from at least 5 per cent for large piles to more than 10 per cent where low piles are used. In the case of direct haul in batches from the yard to the mixer, there are stock-pile losses under the yard piles. In the event that field stock piles are used, it is customary to accumulate materials at the yard for the last mile or so of pavement in addition to the number of pairs (sand and coarse aggregate) of field piles. If, then, X equals the number of pairs of field stock piles used on a given project, the total number of pairs of stock piles used will ordinarily be $1 + X$. But it has been shown that the number of pairs of stock piles used where there is direct haul to the mixer in batches is 1. There is, then, an excess stock-pile loss, where field stock piles are used, of X, the number of pairs of field stock piles, times the average content of a pair of stock piles (where the stock piles are placed about a mile apart, commonly about 4,000 tons) times the average loss,

seldom less than 5 per cent and more apt to be from 7 to 10 per cent, or from a minimum of about 200 tons to a maximum of more than twice that. There is, of course, to be included in calculating the value of material lost in this way, the cost of handling and hauling it to the stock piles.

The Value of the Truck Time Involved.—The cost of the loss of 6 minutes of truck time per batch hauled can be shown in various ways. Thus, if production is at the rate of 40 batches an hour, this would be equal to the loss of 240 minutes of truck time every hour, which is the full time of four trucks. In short, at this rate of production, equal efficiency of operation being maintained under both systems, the difference in the basic

FIG. 51.—First-class modern loaders with trucks in position for loading.

efficiency of the two systems is such that the direct-haul method will save the full time of four single-batch trucks. This is perhaps $40 a day, and in a working season of 120 days would, on a dollar basis, represent about $4,800.

The Value of Materials Lost.—The cost of the materials lost on a 20-mile job, a good season's work, would, on the basis developed above, assuming 2 plant set-ups and 16 pairs of field stock piles, amount to at least $600 per stock pile on some 16 pairs of stock piles, or to $10,000 or more.

The Extra Equipment Involved.—Beside these losses, personnel and investment must be considered. Where field stock piling is

done, the investment commonly is larger than is required for direct haul by the amount of the cost of two loaders. These machines, however, in their present well-developed form, are so new that data on their depreciation are lacking. It is not, therefore, possible to show what repairs and depreciation on the rehandling plant adds to the figure given above, but if rates commonly used on other types of motor-driven moving equipment prevail, this item could hardly be less than $2,000 a year. At least $1,000 must be allowed for operation, gas, oil, etc.

The Cost of Personnel.—The personnel used in rehandling the materials in the stock piles is, in its entirety, an addition to the personnel required where direct haul is used. One man is used on each loader and a man or two about the stock piles. Often extra labor is required for short periods. Taking the season as a whole, few installations of this sort will show an average of less than five laborers engaged in rehandling operations. This, for the season of 120 days, would perhaps amount to $2,400, though labor costs vary a good deal and there are a good many regions where the cost of these men would be less than this.

The General Result.—There is, then, a sum total of over $20,000 involved in the extra costs generated by this system of handling materials on an ordinary 20-mile project. Moreover, these are to be taken rather as minimum figures, for in particular the material losses, the heaviest item involved, may be considerably increased, whereas any material reduction in any of the items is unlikely. In a general way, then, the handicap in cost of operation, under which this system suffers where it attempts to compete with a reasonable length of direct haul in batches, amounts to something like $1,000 a mile, an amount any contractor will do well to consider.

Standby Costs.—This discussion would not present a fair view of this matter if the fact were not added that, where the haul much exceeds 5 miles, the matter of standby truck time comes in to disturb the above calculations. Thus, for a project involving hauls from 1 to 10 miles, to deliver 450 batches a day would require a minimum of 6 trucks and a maximum of 65 trucks. The average requirement would be 36 trucks; so if 65 were furnished, the standby truck time would equal the full time of 27 trucks, which at $200 would be worth $5,400. Where the haul is long, the tendency is, therefore, materially to reduce the disadvantage of field stock piling.

Efficiency of Operation as a Factor.—Moreover, the advantage of the direct-haul method will be reduced and may be entirely lost if the efficiency of operation is not maintained on as high a basis as where the stock-piling method is used. As the length of the haul increases, the difficulty of maintaining high efficiency in the transportation increases rather rapidly; so when this aspect of the case is examined, it may at times appear proper to use the stock-piling method even though a close analysis of attainable cost under both methods appears to indicate the use of direct haul in batches.

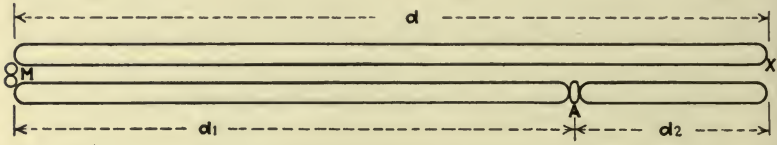


FIG. 52.—Graphical development of relation between direct hand to mixer and hand to field stock piles and thence to mixer.
M, material yard; x, Mixer; A, Field stock piles.

The Use of Other Styles of Truck.—The above deductions have been based on the use of single-batch trucks. This is solely because these are the trucks most commonly used for direct haul to the mixer in batches and from the stock piles to the mixer where the field-stock-pile method is employed. It would have been quite as practical to develop these facts on the basis of the use throughout of two-batch (3½-ton) trucks, when the conclusions would have been about the same. As a matter of fact two-batch trucks are sometimes used in hauling from field stock piles to the mixer and where so used have proved quite as fully satisfactory as where they have been used in stock piling and on direct haul in batches from the material yard to the mixer. Indeed, their first cost appears to have been the principal reason that they have not been more widely used, though their weight has been something of a handicap. The dual rear wheel is, however, proving so satisfactory on paving work that at least the weight of these trucks is likely to appear less of a problem.

Nothing need be said here in regard to the details of the management of the trucks. These have been fully discussed in the previous chapter. They do not differ essentially, no matter which of these systems of operation is used.

The general result of these calculations and deductions is, then, to show the outstanding differences in the transportation

set-up required for these two styles of operation, and of relative cost, the salient points of which may be summarized as follows:

1. The ton-miles of haul is greater under the stock-piling system because wasted materials must be hauled.

2. As all material has to be loaded into the trucks twice under the stock-piling method, the second time under conditions not conducive to easy manipulation of the trucks, a considerable amount of extra truck working time is inevitably involved in the stock-piling method.

3. As the number of trucks which must be used under the system of direct delivery to the mixer increases, long-haul projects develop an amount of standby truck time that tends to offset the advantage which this system has on hauls of ordinary length.

4. The heavy material losses incident to field stock piling tend to make this system prohibitively expensive.

5. The cost of rehandling materials at the stock piles increases the disadvantage of the field-stock-piling method.

6. The long string of trucks required when hauls of unusual length are involved is difficult to manage efficiently. Reduced efficiency increases hauling costs and may even cut production at the mixer. Such a condition tends rapidly to wipe out the advantages possessed by the direct-haul method.

CHAPTER X

THE USE OF INDUSTRIAL RAILWAY IN HAULING TO THE MIXER

It is the general practice, where industrial equipment is in use, to begin laying the pavement at the point on the road which is nearest to the material yard, extending track about as fast as the mixer is able to lay the pavement. As the trains are loaded, they are sent out to the mixer, the batch boxes being lifted off the cars by a light crane and emptied into the skip. In the occasional cases where very large mixers are used, a hopper on the mixer replaces the skip, but this makes no difference in general operating practices, though it somewhat interferes with fast operation by reason of the fact that the higher lift which results adds so much to the time required in handling a batch box that it tends to interfere with the fast operation of the mixer.

Switching.—A greater problem in securing fast, efficient operation is that of expeditiously exchanging trains. Efficient operation naturally presupposes the full utilization of the working day. But, on the projects which have been subjected to rather careful study, it has been found that exchanging trains commonly takes from 5 to 15 minutes, depending on the distance from the mixer to the nearest passing track. There is here, then, a serious problem. If trains are operated on a 12-car basis and if, when material is available, production is at the rate of 45 batches an hour, full production would require 1⅞ trains an hour. But if an average of 10 minutes is lost with each exchange of trains, the actual output tends to fall below 35 batches an hour merely because the working time is cut to 45 minutes or less per hour. The value of time lost at the mixer has been shown to be about 70 cents a minute. The time ordinarily lost by the mixer by the use of commonly accepted practices in handling trains is, then, worth as much as $100 a day and may be worth even more than this. This is quite sufficient to warrant rather close examination of the necessity for the train-handling practices which are in vogue.

Usual Train-handling Practices.—The ordinary practice in laying track is to place passing tracks at convenient intervals along the completed pavement, that is, behind the mixer. These passing tracks are kept within about ½ mile of each other if conditions permit. But as the shoulders on high fills, as well as the cuts, including the space for ditches, are too narrow for a double track, and the fresh concrete is, of course, prohibited ground, the contractor is forced to select, as the locations for passing track, places where either the cut or the fill is so light that the shoulder may be widened at reasonable cost for the temporary accommodation of a second track. This tends to result in rather a random location of passing tracks and often forces the contractor to place them at uneconomical distances apart. When a train has discharged its load at the mixer, it must, of course, return to the nearest passing track before the next train can clear for the mixer. It is clear, therefore, that even if the distance to the passing track is normal, from 1,000 to 3,000 feet, as the average train speed seldom much exceeds 6 miles an hour, the time unavoidably lost in the exchange of trains is a matter of real importance.

Switching Ahead of the Mixer.—Time losses from switching trains can be practically eliminated by maintaining a passing track ahead of the mixer. This can be done readily enough at a moderate expense, because the finished subgrade provides a perfectly satisfactory location for a temporary passing track. To make this system of operation a success it is necessary that the subgrade be kept about 2 full days in advance of paving and that two switches be used ahead of the mixer, one in service and a second which is being moved ahead for the next day's run. Each evening when work is stopped, the subgrade should then be completed for about 2 days' run and the switch for the next day's operations should be in place about 1½ days' run ahead of the mixer. Placing it at this distance ahead of the mixer gives ½ day in which to tear it up and move it ahead without interfering with the paving. With production at the rate of 45 batches an hour, this practice requires that subgrade shall be kept completed about 2,000 feet ahead of the mixer, and that switching shall involve a run ahead of from 1,500 feet in the morning to about 500 feet in the evening. The principal extra expense involved is the time of the extra labor which will be required for

the daily operation of taking up and relaying a forward passing track.

Train Operation When Switching Ahead.—Train operation under this system is simple. The second train should arrive while the first is being unloaded. When fully unloaded, the first train pulls ahead to the passing track and the loaded train follows far enough to bring the last three or four cars that it is hauling opposite the mixer. These cars are then cut off and the rest of the train proceeds to the passing track. As the loaded train clears the switch, the empty train at once starts its return trip to the material yard. At the mixer it picks up the now empty cars left there by the loaded train and takes them back to the material yard. As the empty train pulls away from the mixer, the loaded train pulls into position and remains until it is unloaded, when the same procedure is repeated. As the distance to the passing track ahead will, under these conditions, vary between about 500 feet and about 1,500 feet, the exchange of trains under this system of operation ought not to take more than from 5 to 10 minutes; so if from two to four cars are left at the mixer, this should keep it busy until the switching is completed, but a car or two more or less dropped from the loaded train as it passes the mixer is not an important matter. The main purpose is to keep the mixer from losing time, and by this method this can be accomplished at a reasonable cost.

Shifting Cars by Hand.—It may be observed that shifting the loaded cars at the mixer is a task of no great moment if the grades are under about 4 per cent, but on steeper grades special precautions must be taken to hold the cars. If the ground is level, the work can be done easily enough by two men. If the mixer is working up a grade, the cars should be left a few feet higher up on the grade and shifted down to the mixer. If the mixer is working down a grade, the extra cars should be pulled by the mixer, shifting again being downhill but from the other end of the string. Moderate grades can, in this way, be worked rather more easily than level ground.

Spotting Trains Ahead of Mixer.—Another device sometimes adopted in avoiding the delays incident to shifting trains is to begin operations each morning by sending out two trains as close together as they can be run. The first of these two trains should in reality be a double train and should be handled by two engines, one of these engines being at the rear of the train operating as

a pusher and the second in the middle of the train. This train should pull by the mixer. The second train, a train of ordinary size, should follow as closely as possible. Upon reaching the last passing track, the engine on this train should be shifted to the rear of the train which it should then push into position at the mixer. Upon arrival at the mixer, the rear engine on the first train should be uncoupled from this train and coupled to the second train, and the engine which brought up the second train should be released to return at once to the material yard. This begins the day's work with two trains of cars and one locomotive ahead of the mixer and a full train at the mixer. Where the grades are moderate, there will then be perhaps 16 to 18 cars (32 to 36 batches) ahead of the mixer, or enough to feed the mixer for from 45 to 50 minutes. If grades are light, it may be possible to place 24 to 30 cars ahead of the mixer; in this way, if 8-ton engines are used, enough to feed the mixer from 60 to 90 minutes. The purpose in placing these cars ahead of the mixer is to have them available during the interval usually lost in switching.

When the second train, that is, the train sent out for immediate service to the mixer, is emptied, it starts the return trip to the material yard. As it moves away from the mixer, the locomotive ahead moves the string of cars, lying between it and the mixer, into position for unloading and remains at the mixer until the next regular train from the yard arrives. As this train pulls in, the first train again moves out of the way but leaves the cars which have been unloaded to be attached to the incoming train and by it carried back to the mixer. This operation is repeated after each train from the yard is unloaded. Returning empties with trains enroute to the yard reduce the number of cars left with the head locomotive, as far as the foreman deems desirable. Finally, depending somewhat on the grade, when all but from two to four or five of the cars which were initially placed ahead of the mixer have been unloaded, the forward engine with such empty cars as remain should return to the yard with a regular train, stopping only to drop the remaining loaded cars at a point from which they can be shifted by hand to serve the mixer.

Number of Double Trains Required.—It will be apparent that the virtue of this procedure will depend on whether there is enough rolling stock on the job so that an engine and two full trains of cars can be used in this way, and also on the number of cars carried per train. If 18 cars are run out in the double train,

the supply will feed a well-operated mixer from 45 to 50 minutes. Switching delays vary in length from 4 to 5 minutes up but commonly average about 10 minutes. To maintain a consistently high output, about every sixth train sent out would, under these conditions, have to be a double train, to be run ahead of the mixer. If, on the other hand, the grades were such that 30 cars could be carried out in the first train, this would feed the mixer for from 75 to 90 minutes; so only every eighth, or perhaps every ninth, train would have to be a double train. The details of this system must be worked out from day to day on any job where it is used, and these will inevitably depend on the equipment available and the physical capacity of yards, track, etc. This system, however, while offering a means of saving a great deal of mixer time now commonly lost on industrial jobs, has the disadvantage of presenting so complicated a problem in train scheduling and train control that few foremen appear to be able to make it work out in an altogether satisfactory fashion.

Spotting Cars Ahead of Mixer.—Another method, particularly satisfactory wherever the grades are light, is to determine what rate of delivery can be maintained during the hours when the mixer is operating and what delays, due to switching, must be expected, and then, with these data and definite knowledge of what rate of production the mixer can maintain when it is properly served, to make night delivery of enough cars to supply the difference. The cars, delivered at night, can be spotted at intervals along the distance to be covered by the next day's run, and then shifted into position at the mixer by the regular trains, there to be moved as needed by hand. Empties are carried back to the yard by the regular trains. If this is deemed preferable and one is available, an engine can be left ahead of the mixer to shift these cars, running back to the nearest passing track with the accumulated empties with every fourth or fifth regular train. Empties spotted on the passing track are handled by the regular trains. This method is rather easy to apply. Thus, if 350 batches a day can be delivered by available engines during the regular working period and 450 batches are needed, 100 batches, 50 cars, must be spotted ahead during the night. There is, of course, no objection to this if good batch boxes are used, as the cement is in a watertight compartment so that even a heavy rain should do it no damage. Neither is the item of expense for extra equipment of much importance, for the extra cars and

the extra batch boxes should cost less than one good locomotive, whereas the savings which would result from having the extra batches available should, during a good working season, amount to a good many thousand dollars.

Results to Be Expected.—In practice it is probable that no one of these systems will develop full production, but any one of the three, if carefully followed until all of the men who are operating under it become thoroughly familiar with it, will develop a considerable improvement in production over what is now common. As between the usual rates of production where industrial railway

FIG. 53.—A typical derailment.

is used, commonly little if any over 30 batches an hour, and the rates which ought to be had, there is for a good season's work a difference in profit amounting to well over $10,000. This, of course, is quite enough to justify a good deal of attention to perfecting a system of material delivery which will yield a better rate of production than is now common where industrial railway is in use.

The Effect of Accidents.—A consistently high rate of output at the mixer requires an equally consistent high rate of material delivery. The accidents which occur in connection with the delivery of material by industrial railway are peculiarly destruc-

tive of uniform delivery, because they so often stop delivery entirely. The derailment of a few cars may tie up the line for half an hour and the derailment of an engine may tie it up for even a longer period. Ordinarily there is no means of quick communication between passing tracks; so if help is needed, some one must walk to a point from which it can be called and this may easily mean walking a mile or two. The installation of a job telephone system would tend to improve train operation materially, as well as to facilitate obtaining relief in emergencies, and these occur rather often, but a matter more necessary for the general improvement of delivery by industrial railroad is adequate attention to track.

The Track.—Commonly the track is laid on the shoulder. The general practice is to delay its placement until the subgrading

FIG. 54.—Typical industrial railway track as installed on a concrete paving job. The batch boxes were spilled in a derailment.

has been practically completed. This, on the whole, is advisable, for the preliminary rough grading seldom is accurately accomplished, and as a result more or less material must be moved to and from the shoulders in the course of bringing the subgrade into proper condition for surfacing. This leaves the shoulders rough and uneven, some of the shoulder area being reasonably solid, but much of it being covered with loose piles of

freshly moved earth. Often nothing more is done to the shoulders in preparing them for the track than to smooth them down enough, either by hand or by means of a light blade grader, so that the track as first laid will be fairly smooth. This condition, bad as it is, becomes rapidly worse under operation, particularly if there is any wet weather, for water collects around the ties, which usually are entirely too light to carry the locomotives, leaving the depressions in which they lie wet for some time after the subgrade is dry enough to permit paving. The obvious solution is heavier and wider ties, a more perfect preparation of the bed on which the track will rest, more care in laying the track, and more attention to its proper maintenance. The shoulder on which the track will rest ought to be rolled, and the subgrade on which the track rests should be crowned so that most of the water which falls on it will run off. Where there are soft spots in the subgrade, the track should be ballasted. Above all, the track should have constant maintenance.

The Effect of Wet Weather.—From extended field observations, the popular belief that after a rain the industrial railway can be used more quickly than trucks appears to be largely a fallacy. As a matter of fact, a disproportionate percentage of the derailments which involve the loss of material is directly traceable to the fact that the subgrade is so often ready to receive paving before the soil under and around the ties is dry enough to carry the trains. The tendency to use track too soon after rains is also a large factor in creating the bad track conditions which are responsible for slow train movement. The truth of the matter appears to be that if reasonable consideration were given to these matters, trains would be kept off ordinary industrial tracks as used in paving jobs for some days longer than is now the practice. Just how much longer would depend much on soil conditions, but it is apparent that higher train speeds would be possible if the track was not used quite as soon after heavy rains.

The Cost of Good Track Laying.—Admittedly, careful work in laying track will cost something, as will thoroughgoing maintenance. But the difference between the direct cost of proper track laying and proper track maintenance and the direct cost of that grade of performance in these fields which is found on most going projects appears slight when compared with the value of the time that is lost at the mixer, to say nothing of the value of the materials which are destroyed in the wrecks and derailments

that are a common feature of this work, and the extra trains required by reason of the slow operating speed imposed by ordinary track conditions. Indeed, proper track laying and first-class track maintenance, beside requiring a little roller time when the subgrade for the track is being prepared, ordinarily would add not more than one man to the track-laying crew and not more than two or three men, depending on the length of the track, to the maintenance crew, or under ordinary circumstances, from $10 to $15 a day. But time lost at the mixer through the nondelivery of materials, based on jobs which have been subjected to careful study over extended periods, has ranged from a job aver-

FIG. 55.—Wrecks often cause the loss of much material. This one was due to spread rails.

age of ½ to 2 hours per day and appears to average about ¾ hour per day. Most of this failure to get material to the mixer has been due to poor track which has caused slow train movement, derailments, and wrecks. This average lost time at 70 cents a minute is worth over $30 a day; so it is apparent that a somewhat heavier expenditure on track laying and on track maintenance would be highly profitable if it served only materially to reduce these delays.

No extended reference will be made to the loss of material as a result of wrecks. Such losses, however, are of frequent occurrence and cost a good deal. On one project studied during the summer of 1925, 434 sacks of cement with coarse and fine aggregate were lost in the 118 days during which the mixer operated. This was a higher rate of loss than would be found on most jobs

but serves to show that the direct loss due to poor track may be a serious element in the cost structure. Tables VI and VII give studies of time losses on typical industrial railway jobs (*Public Roads*, p. 231, December, 1925).

TABLE VI.—OPERATION TIME LOSSES ON INDUSTRIAL RAILWAY JOB

Date (1925)	Proportion of working time mixer was in operation	Percentage of working time lost due to various causes				
		Waiting for train	Train derailed	Slow operation of mixer	Waiting for materials at railroad	Miscellaneous
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Mar. 9	28.0	45.4	26.1	....	....	1.0
Mar. 10	34.9	35.0	....	0.7	29.2	
Mar. 11	51.9	....	....	....	48.2	
Mar. 11	50.8	48.5	....	.7		
Mar. 12	44.6	....	....	.2	42.3	13.1
Mar. 13	54.4	28.4	....	....	....	18.0
Mar. 13	52.0	44.7	....	1.4	....	2.4
Mar. 14	63.4	25.6	....	10.7		
Mar. 16	66.1	16.7	....	....	....	17.3
Mar. 17	62.6	13.4	....	....	....	23.9
Mar. 17	44.4	54.2	....	1.4		
Mar. 18	30.5	69.1	....	.6		
Mar. 18	42.2	56.3	....	.5	....	1.3
Mar. 19	80.5	12.4	....	....	....	7.1
Mar. 19	58.5	40.0	....	.2	....	1.2
Average	51.0	32.6	1.7	1.1	8.0	5.7

TABLE VII.—OPERATION TIME LOSSES ON INDUSTRIAL RAILWAY JOB

Date, 1925	Proportion of working time mixer was in operation	Percentage of working time lost because of various causes								
		Handling batch boxes	Spotting cars	Switching	Mixer trouble	Slow operation of mixer	Moving mixer	Water supply	Fuel supply	Miscellaneous
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sept. 26	44.7	1.7	5.5	....	3.0	3.8	5.1	....	36.2	
Sept. 28	46.5	5.3	....	37.3	....	....	10.9			
Sept. 29	67.6	10.9	....	9.7	....	....	11.8			
Sept. 29	61.7	9.7	....	5.9	....	5.8	10.7	....	....	6.2
Sept. 30	43.3	6.1	1.0	....	....	4.0	20.6	....	....	25.0
Sept. 30	63.0	11.3	7.3	....	....	6.9	5.7	....	2.5	3.3
Oct. 1	69.2	3.2	3.1	17.9	1.9	....	.9	....	3.8	
Oct. 2	45.2	16.0	9.6	....	9.9	1.7	....	....	2.2	15.4
Oct. 3	41.1	1.1	18.0	....	....	4.6	....	....	....	35.2
Oct. 9	55.1	6.5	2.8	8.4	....	6.7	20.5			
Oct. 9	49.0	2.0	....	10.0	1.9	5.6	31.5			
Oct. 10	35.1	.9	4.8	54.1	.5	2.2	2.4			
Oct. 12	39.0	5.1	....	11.2	....	5.2	5.4	....	....	34.1
Oct. 12	55.2	10.0	....	22.7	....	7.5	2.5	....	....	2.1
Oct. 13	53.0	5.6	....	22.5	12.5	2.2	2.4	....	....	1.8
Oct. 14	49.4	6.6	....	17.9	....	.6	1.2	22.3	....	2.0
Oct. 15	60.3	11.0	....	13.8	5.1	....	9.8			
Oct. 15	40.9	1.4	....	10.0	1.2	20.2	26.3			
Oct. 16	65.6	3.2	....	7.8	....	2.7	20.7			
Oct. 16	40.4	4.0	....	2.0	39.7	1.1	2.8	10.0		
Oct. 16	77.0	2.6	....	.9	12.2	5.3	....	....	....	1.8
Average	52.5	6.0	2.5	12.0	4.2	4.1	9.1	1.5	2.1	6.0

NOTE.—No time losses because of rain or similar causes are included in this study.

Track and Equipment.—For hauling material by industrial railway, enough track is required to cover the longest distance that will prevail between possible material-yard sites and mixer set-up, together with necessary turnouts, passing tracks, etc. The track ordinarily is furnished in sections 15 feet long equipped with steel ties, fish plates, etc., 20- and 25-pound rail are standard.

The cars used on this work are merely a steel frame supported on four wheels, the frame being made long enough comfortably to carry two batch boxes. The batch box may be a homemade wooden affair or a well-built steel box. In either case, it may have three compartments, one for coarse aggregate, one for sand, and one for cement, or if aggregate is loaded from a good volumetric or a good weighing device, only two compartments. There are two styles of these boxes, tilting and bottom dump. On the tilting variety the point at which the bale is attached is set below the center of gravity so that when the lock is released, the batch box turns over and empties the charge. The bottom-dump variety has two doors in the bottom which are operated by taking the lifting load off them and throwing it onto a bale attached to the sides of the box, an operation performed by the crane. The first type is almost always used where the batch box is emptied into the skip on the mixer.

Delivery to the mixer is handled by locomotives of the gasoline type. The 6- or the 8-ton types appear to be the most popular, though other sizes are available. They are well built, rugged, and dependable.

The Amount of Equipment.—The amount of equipment, that is, the number of locomotives, cars, batch boxes, etc. which must be supplied to a job depends on the length of haul, on the ruling grade, and on the rate of production it is desired to maintain. Of these the first governing condition is, of course, the rate of production. If, for purposes of illustration, it is assumed that production at the rate of 45 batches an hour will be attempted, provision must be made for equipment ample to deliver this amount of material. In level country, that is, when grades do not exceed 1 per cent, a good 8-ton locomotive can handle a 15-car train, or 30 batches. To maintain full delivery at the mixer it is, then, under these conditions, necessary to deliver one and one-half trainloads an hour. If, on the other hand, the ruling grades run from 5 to 6 per cent, such a locomotive will ordinarily handle trains of only eight cars. If there are only one or two heavy grades, it often is economical to station an extra engine at these grades to operate as a helper, confining its work to helping in the movement of trains there. This practice permits the use of a train length governed by the grades on the rest of the work.

Advantages of Long Trains.—The use of long trains has the advantage of reducing the number of trains. It also reduces the time lost in switching and saves a few men, as it is customary to send out at least one man beside the engineer with each train. This is almost a necessity, as derailments are very common and an extra man is needed in getting cars back onto the track. Perhaps an even more important consideration in using long trains is the effect that train length has on train movement. A 12-car train carries 24 batches. In order to maintain production at 45 batches an hour, a batch must be used every $1\frac{1}{3}$ minutes. A train must, then, be supplied every 32 minutes. On this same basis the batches on an eight-car train will be used in about 21 minutes, and the batches on a six-car train in 16 minutes. It requires a good deal of skill in handling trains, to say nothing of the skill involved in laying out the passing tracks, yards, etc., in order to maintain traffic over a single-track line with trains operating in both directions on what is practically a 30-minute headway. Indeed, very few superintendents have ever succeeded in doing it over track of any length. To cut the train length down complicates the problem, because it decreases the headway. Indeed, it is hardly going too far to say that production simply cannot be maintained over a single track on a six-car train basis, because the headway between trains is too small.

Round-trip Train Time.—The time required in handling a train of 12 cars is about as follows:

	Minutes
Loading 24 batches of aggregate	10 to 15
Loading 24 batches of cement	10 to 15
Switching per trip	10 to 20
Unloading at mixer (at rate of 45 batches per hour)	32
Train time, exclusive of haul	60 to 82
Travel time for each mile of haul, at 4 miles per hour	30

If, as a fair average of good performance, it is assumed that 75 minutes represents the time per trip spent on operations which are unavoidably performed in connection with loading, unloading, switching, etc., it will be apparent that on a 1-mile haul the round-trip time will be about $1\frac{3}{4}$ hours. But as the working day commonly is limited to 10 hours, the trips per train will be $10 \div 1\frac{3}{4}$, or $5\frac{5}{7}$. In practice fractional trips are not made; so

the performance of the train is by these ordinary working practices limited to 5 trips or to a trip every 2 hours. Now if the trains are carrying 24 batches, 1⅞ trains must be delivered per hour to maintain production at 45 batches an hour. Therefore, as something over three trains are required (½ train equals the delivery per train unit per hour and 1⅞ ÷ ½ equals 3¾, the number of trains required), four must be supplied if full production is to be had.

If the haul is 6 miles, the total round-trip time, on the same basis, will be about 4¼ hours, or, because fractional trips cannot be made, two trips per day, or one trip every 5 hours. By the same mathematical process used above, it becomes evident that 10 trains will then be needed if full production is to be kept up against this haul. If 10 trains are to be operated, 10 locomotives must be used and 120 cars with 240 batch boxes must also be provided. Commonly it is not good policy to provide any more equipment than is needed to meet the requirements set by the maximum haul. On the other hand, the equipment as here worked out would serve only when grades are light. For higher grades additional locomotives must be provided to make possible a rate of material delivery which would maintain production.

There is so much variation in the speed at which trains operate, a condition which arises from the fact that the track varies from very poor to moderately good, that it is not possible to make up valuable tables showing equipment requirements for various lengths of haul and various grades. The above method of solution, when applied to the operating practices, train speed, etc. which a contractor uses on his own work, will yield reasonably accurate data on how his work should be equipped in order to meet any specific construction plan.

Some Objections to Industrial Railway.—Industrial railway is expensive, but while, on the basis of expense alone, its use would be of doubtful expediency, there are even more vital objections to it, of which the difficulty of obtaining extra equipment when special hauling conditions are encountered, except by purchase, may be noted as one, and the fact that on grades steeper than 6 per cent, the amount which can be hauled by one locomotive is small is another. The high cost of moving from job to job also is a valid objection to the use of industrial railway equipment. Some 450 tons of rather unwieldy material are involved in the equipment needed on a 6-mile haul (low grades basis). To haul

this from storage to railroad station, to load it on the cars, to ship it, to unload it onto the trucks, to distribute it along the road where it is to be used, to take it up again, and to place it in storage are all expensive operations and in their total involve a sum of real importance in the cost structure. It is not possible to do more here than to mention the operations which must be performed, for the conditions surrounding each one differ so much from job to job that no general figures can be of value.

The popular impression that industrial railway offers an economical solution of the paving contractor's hauling problems appears to be based on the well-known fact that rail transportation shows a surprisingly low ton-mile hauling cost. The point likely to be overlooked is that this low cost is had over track maintained in place over long periods of time. The paving contractor faces no such fortunate condition. His track is used only for a brief interval, after which it must be pulled up and taken to a new location. Even then, the actual cost of hauling over it is low, but the cost of rebuilding and then tearing up and moving the line with every job undertaken introduces cost elements both large and difficult to predetermine.

Finally, it may be remarked that while some contractors have had fair success with industrial railway in the paving field, it has never come into anything like general use in any of the other branches of highway construction. Any investment in industrial railway must, therefore, under all ordinary circumstances, be viewed as a single-purpose investment. If no concrete pavement work is to be had, this equipment normally will lie idle.

CHAPTER XI

FINAL FINE GRADING

In discussing the fine finishing of the subgrade as it is carried on ahead of the paver, reference was made to the fact that the fine grading should leave the subgrade just a little high. The fine finishing ought to be kept from 500 to 1,000 feet in advance of the mixer; so if material delivery is by truck, which is the case on the great majority of paving jobs, this closely finished work

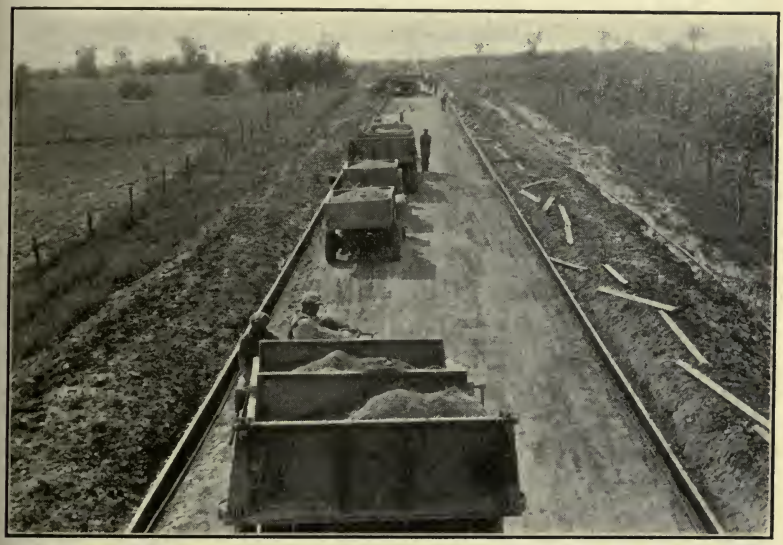


FIG. 56.—The delivery of materials to the mixer unavoidably affects the shape of the subgrade. Note turntable in operation in background, reinforcing steel next to forms and parting strip on the shoulder. Everything is in position for a good run.

is normally subjected to truck traffic for about a day before it is reached by the paver. If the subgrade is well dried out, the distortion which results from hauling over it is relatively small, but if only the surface is dry, the underlying material being somewhat plastic, there may be a good deal of distortion. It is, of course, essential that when the concrete is placed, the subgrade

shall be of correct shape and that it shall be cut to the proper depth below the top of the forms. No matter how carefully the subgrading is done, there is, then, some work to do on the subgrade just before concrete can properly be placed on it.

The Fine Finisher.—The distortion of the fine grading which results from the delivery of materials is in the nature of ruts where the trucks have run and slight bulges between and at the side of these ruts. If the subgrade is well dried out, the ruts will be very slight and the bulges may be almost entirely absent. If the underlying material is a little plastic, however, both the ruts and the bulges are likely to be of more consequence. As a rule, specifications require that these high areas be reduced to grade, a moderate tolerance being, in some instances, permitted. There commonly is no requirement that the low areas shall be filled. As a result, the major effort is toward the reduction of the high areas, and properly to accomplish this a heavy fine finisher should be attached to the mixer to be dragged along by it whenever it moves. In ordinary clay and loam soils this tool will cut reasonably close to exact grade if the cutting is light, $\frac{1}{8}$ to $\frac{1}{4}$ inch, but not even the use of a tool as heavy as this will insure a good subgrade if the amount of material to be trimmed off is large or if the ground is baked and hard. In short, this tool is not a subgrading machine. The subgrading should be accurately done ahead of the mixer by tools heavy enough and strong enough to do the work correctly. It is just what its name implies, a planer or fine finisher. If through careless fine grading ahead of the mixer, however, or because there has been some distortion of the subgrade as a result of the delivery of materials, there is more material to cut than this machine will handle comfortably, it may be heavily weighted down and so forced to make an extra-deep cut. Bags of sand may be used for this purpose or the puddlers can stand on it while the mixer is moving it. Handled in this way the planer will take off quite a little more material than it will take off without weighting. If it is necessary to load it in this way, there is some danger that the main carrying beams will bend a little. This is of no particular consequence so far as the machine itself is concerned, but any sagging of the main beams naturally tends to drop the blades and so to make the machine cut low. For this reason, particularly when a relatively permanent load, such as a number of sacks of sand, is put onto the machine, they should be placed as close as possible to the ends of the machine.

Sprinkling.—Heavy sprinkling under and around the mixer helps to make the cutting easier. If sprinkling is to be done, it must, however, be done far enough in advance of moving the planer so that the water can permeate the ground to a depth rather greater than the depth to which the soil must be removed. When well weighted down and working in properly wetted loam or normal clay, this machine can take off a cut ½ inch thick, but the advance preparation of the subgrade should never be done so carelessly that any such amount of material must be handled. In wetting the subgrade for this purpose, some care should be exercised to see that the ground over which the mixer's crawlers must pass is left dry. Otherwise traction may be partially lost, with the result that the mixer will skid. Under any circumstances, moving ahead with the fine finisher requires a good deal of power and good traction, but when a relatively deep cut is being taken, good traction is doubly important. If the traction is poor, time is lost and the subgrade is more or less torn up.

When the cut to be taken off is of some depth, ½ inch or so, the subgrade can properly be sprinkled twice or three times before the fine finisher reaches it, sprinkling around the mixer, under it, and for a distance back of it equal to the length of one or two moves. This sprinkling should be done after each move, as this has the effect of overlapping the various applications of water. This is better than to apply the necessary water in one wetting, for it gives it more time to penetrate and develops the desired moistening of the soil without producing an unpleasantly muddy surface.

Low Areas.—A subgrade properly cut out by a fine finisher of this kind should show no point more than ⅛ inch high. This tool does not, however, fill low areas though it tends to deposit loose material in these low areas. If the subgrade has been sprinkled, the cuttings deposited are moist; so if the low areas are of any depth, as in the case of ruts 1 or 2 inches deep, the material which has been deposited can be lightly tamped to a very satisfactory compaction by means of an ordinary hand tamp, and additional moist cuttings added if this is desirable. If the ruts are shallow, ½ inch deep or less, tamping is likely to be considered unnecessary, particularly if the subgrade is prepared as discussed in previous chapters. The subgrade resulting from these practices is closer to correct grade at all points than can be expected under any other system which has been observed

in operation under field conditions. The work is handled rapidly and, if the fine finishing was properly done, requires the time of only one man who does the work of filling and tamping depressions if this is necessary, keeps the subgrade wet enough to cut well, and removes the cuttings from the planer.

Homemade Templates.—Homemade tools are often used on this work. All such tools used in checking and finally correcting the subgrade are open to more or less obvious objection. As a general rule, those which are supposed to cut the subgrade to exact grade lack both weight and strength. The result is that they drag over the high spots which then have to be removed by means of mattocks and shovels. At best the close work required here cannot be done very accurately with these tools.

Homemade scratch templates are found in use more often than homemade cutting templates. Sometimes a heavy scratch template is dragged by the mixer, or a lighter template may be used and dragged by hand. When so dragged over the subgrade, it is assumed by scratching the high areas to indicate where and by how much these must be reduced. Naturally it can give no indication of the amount of material lacking in low areas. The high areas which the template indicates are supposed to be taken off by picks or mattocks and shovels, but the ease with which the marks left by the template are obliterated makes the trimming inaccurate. As a result, the scratch template has to be used a number of times or considerable inaccuracy in the finished subgrade results. If it is used a number of times, this takes extra time and tends to interfere with the steady progress of the mixer. It takes very little interruption of the mixer to generate losses which in their accumulation cost much more than a good planer.

The drag template, a light plank cut to proper shape, is sometimes used instead of the scratch template, but practices in its use are very similar, except that where it is used it ordinarily is moved back and forth until it rides free over the subgrade.

Checking Templates.—The blades on the subgrade finisher wear rather rapidly. Wooden tools sag and warp. The heavy homemade cutting templates often accumulate a permanent sag due to being heavily loaded when wet, to warping, etc. The points on the scratch templates wear off. It is not necessary to check these tools every day, but it is essential that they be checked at rather frequent intervals. To check them, they

should be raised off of the ground and set on horses or some similar support so that they will be checked under the same conditions as to support that prevail while they are in use.

The Effect of High Subgrade.—The general purpose in the use of any of these tools is to avoid thin spots in the pavement. These are supposed by many to be important because of their effect on the adequacy of the pavement as a structure. It is now the general practice of engineers to use a thickness of 6 inches over the central area of concrete pavements. The reduction of any considerable extent of this to 5 inches reduces the strength of the pavement here to about 70 per cent of the

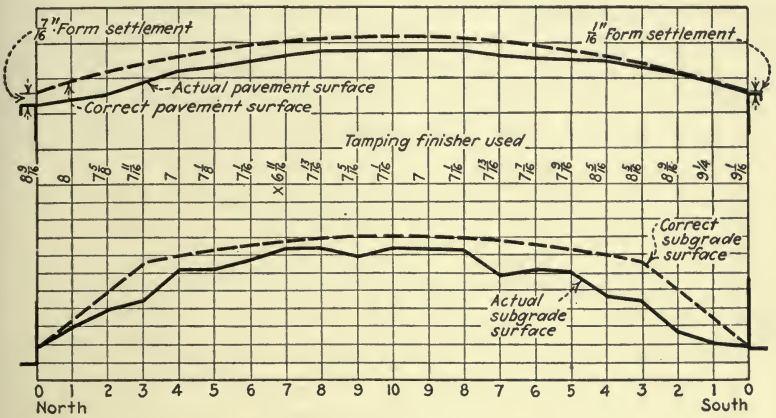

7/16" Form settlement
1/16" Form settlement
Actual pavement surface
Correct pavement surface
Tamping finisher used
Correct subgrade surface
Actual subgrade surface
0 1 2 3 4 5 6 7 8 9 10 9 8 7 6 5 4 3 2 1 0
North
South

FIG. 57.—Fair subgrade.
x, pavement thin because of form settlement.

strength which the design contemplated. Extended field measurements show, however, that high subgrade ordinarily occurs only in relatively small areas and that while the accumulation of errors from this and from other causes often exceeds an inch, the subgrade is rather a minor factor in causing this condition. Moreover, while if thin areas are large their effect in reducing the strength of the pavement is out of all proportion to the amount of material involved and to the cost of reasonably accurate work, the fact appears to be that thin areas generally are small and probably of no great consequence, in short, deserving of no particular consideration. Put in a little different way, the thin areas of ordinary dimensions and thick areas seem to be so related as to position that the general effect on the structural adequacy of the pavement probably is of little consequence.

The heavy fine finisher is the only tool which can consistently do the work of final fine finishing with reasonable accuracy at a reasonable cost; so where the subgrade is composed of material

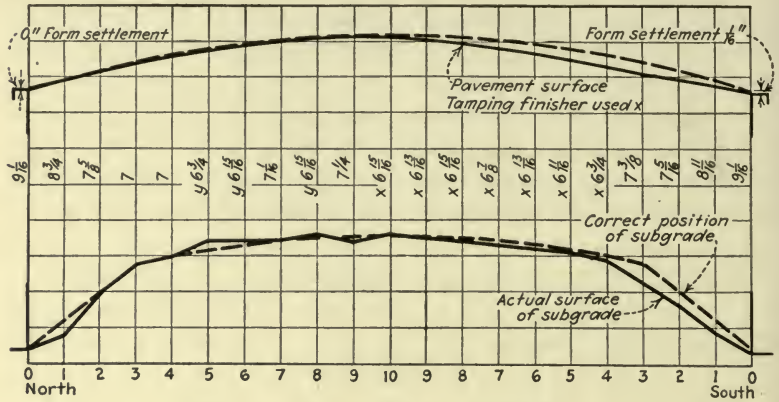


FIG. 58.—A generally good subgrade.
x, pavement thin because of inaccurable finishing.
y, pavement thin because of high subgrade.

it will handle, it is the only tool which should be used on the work. Unfortunately, it does not work well if there is much stone or large gravel in the subgrade, and when such material occurs,

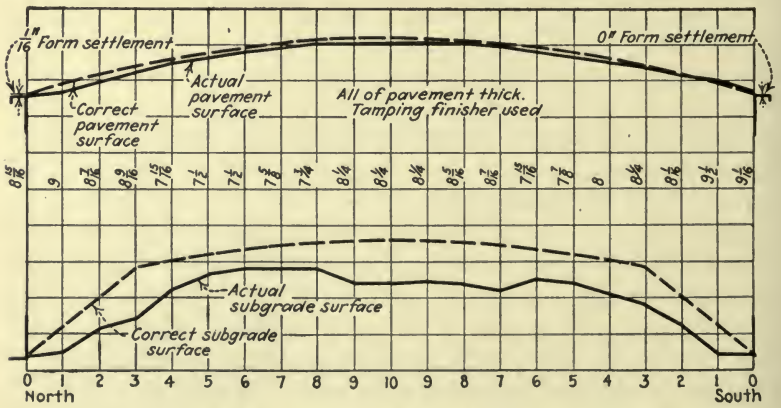


FIG. 59.—The effect of poor subgrade on pavement thickness.

hand methods must be resorted to. Figures 57 to 59 show typical results which have been secured in the final treatment of the subgrade.

Cause of Inaccuracy When Homemade Tools Are Used.—The rather serious inaccuracy in finish which results where homemade tools are used appears to arise from two causes: first, the lack of positive action by the tool itself; and second, light construction which permits more bending of the tool than is readily recognized. Scratch and drag templates often ride over high spots, dragging visibly but not enough to raise the ends off the forms. As a result, work is passed as satisfactory which, in fact, is not. Of course, none of these tools do anything toward reducing the low areas. The heavy fine finishers cut to grade or obviously ride high, lifting one or two wheels off the forms, which makes any failure correctly to reduce the subgrade at once apparent. In such cases, if no tolerance is allowed, the mixer can be run ahead again and a second cut taken off. There is, then, with careful inspection no reason for leaving any high spots in the subgrade when this tool is used.

Filling Low Areas.—As to filling low areas, which the above graphs show to be much more conspicuous than high areas, the general construction policy must govern. The homemade tools are at a disadvantage here in that neither the amount nor the depth of the low areas are indicated by them. The heavier manufactured tools partially fill such areas and, when sprinkling is properly done, do this with moist earth readily compacted by a hand tamp, if that is considered necessary, and if not, by the workmen as they move about over the completed subgrade. If the general practices which govern the final work on the subgrade permit of it, low areas can be quite completely filled in this way, for the moist cuttings taken out by the finisher are an ideal material with which to work.

Handling Mixer to Permit Work on Subgrade.—The job objective is to keep the mixer running at full capacity all the time. On the other hand, the subgrade must be finished to its correct shape before any concrete is placed on it. If the final finishing of the subgrade takes some time, as it will if the finishing ahead of the mixer is at all carelessly done, or if the hauling equipment has somewhat distorted the work, the final adjustment of the subgrade will interfere with the operation of the mixer unless some provision is made to avoid this. The boom on the mixer is about 20 feet long. It is customary to standardize operation somewhat, as, for instance, to move after each sixth batch. To avoid conflict between the operation of the mixer and completing the fine

finishing, it is, then, only necessary to harmonize the job practice in moving the mixer and the work of final fine finishing. This can be done rather easily by first standardizing the operation of the mixer on a basis which provides for moving after the concrete for about a 10-foot strip of pavement has been placed. If standard 18-foot Maricopa pavement is being laid, four five-bag batches of ordinary proportions will lay about 9 feet of pavement. Four six-bag batches will lay about 11 feet. The mixer should, then, be moved after each fourth batch is placed. If, then,

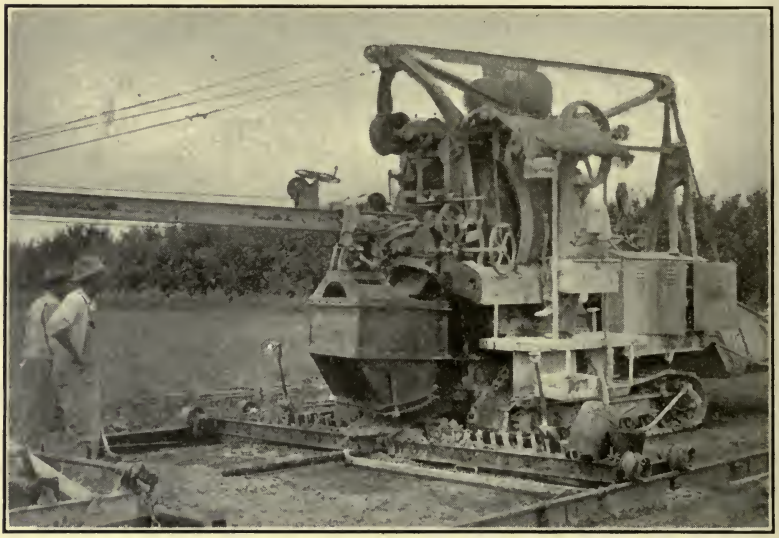


FIG. 60.—A first-class, six-bag paver with fine finisher (often called subgrade planer) attached. Note parting strip and device for insuring that it shall be placed at a proper distance from the form.

pouring is done from near the end of the boom, a space from 10 to 12 feet long next to the mixer is always available for the final adjustment of the subgrade without in any way interfering with placing concrete. As laying four batches of concrete will, under fast operation, require from 5 to 6 minutes, operation under this system permits the management to provide a force which can prepare the subgrade, lay reinforcing steel, and set parting strip while the mixer is operating. The number of men to be used will depend on the number of operations there are to perform, but as the rather simple expedient of dividing the area under the boom into one area where the mixer can work without interfer-

ence and a second area where final finishing, steel setting, etc., can be done without interference, a definite time interval is provided for performing the latter operations, and the problem of the management in selecting the proper number of men for this work on a basis which insures that they shall be steadily occupied is much simplified (Fig. 60).

CHAPTER XII

THE OPERATION OF THE MIXER

The basic idea underlying the organization of modern manufacturing enterprises is that raw materials shall flow into the plant, through it, and out of it as a finished product in a smooth even stream. Commonly, the volume of the outflow is governed at some point by the rate at which some one process can be completed. Naturally, perfect operation would suggest that the capacity for production shall be equal throughout all of the processes. This is not an entirely practical way of operating, however, for, under such an arrangement, to stop any operation has the effect of stopping all operations equally. On the other hand, it is so obvious that a uniform productive capacity throughout the whole of a series of interdependent production operations is basically the most economical relation which can be had that the production manager must approach this as closely as is practical. To accomplish the best results, then, one element in the production series should be set up as the key producer and the capacity at other points in the series of operations incident to production kept enough greater than the productive capacity of the key producer so that short delays need not affect the output of the key producer.

The Mixer—the Key Producer.—On a concrete paving job the mixer should ordinarily be used as the key producer, and if operation is conducted on this basis, the productive capacity at other points in the productive series must be governed accordingly. The productive capacity of a five-bag mixer (1-minute mixing cycle) may be taken at 48 batches an hour. The productive capacity of the new six-bag mixers seems to be about the same. The capacity of the unloading crane, the batch-measuring device, the trucks, and the finishing machine should, then, exceed 48 batches an hour by whatever amount a careful analysis of work of this sort shows to be necessary in order to wipe out the effect of small delays incident to the operation of these machines and to the conduct of the job as a whole. Take the batch-

measuring device as an illustration. If it could produce only 48 batches an hour, one batch every 75 seconds, it is apparent that if a truck due now should come in 2½ minutes late, two batches would be lost. A loss of this kind, under the presumptions laid down, would be unrecoverable, because, the rate of production here being in exact harmony with production at the mixer, the batcher could not catch up this loss, even if there were enough extra trucks available so that no trouble need arise because of inadequacy here. Moreover, if the productive capacity in all of the operations is exactly equal, the loss of time by any one will not only reduce production all along the line by just that amount, but as it will generally happen that such losses occur separately rather than simultaneously, each separate operation will tend to increase the amount of time unavoidably lost by the job as a whole.

Surplus Output Capacity—Batch-measuring Plant.—On the other hand, again using the batch-measuring plant as an illustration, if the time required to put on a load is ¼ minute instead of 1¼ minutes, and a truck arrives 2½ minutes behind schedule, two or three trucks possibly coming in together, the batch-measuring device can "catch up" this loss, as far as it is a factor in maintaining production, before it has finished loading the third truck! This same general principle holds throughout the whole job. Some surplus productive capacity at all other points is desirable, if time losses which affect the whole job are to be limited to the key producer. This surplus productive capacity may be in the one piece of equipment used as in the case of the batch-measuring device, or it may be secured by using extra units, as was brought out in the discussion of the truck supply. It is important, however, that it be secured in one of these ways.

Coordinating Operations.—In a large manufacturing enterprise a great deal of study is required in order to arrange the productive capacity of the machines effectively, primarily because the number of production operations which must be harmonized is, as a general thing, large, but on a paving operation the task is not an outstandingly difficult one because the number of operations to be harmonized and coordinated is relatively small. The objectives are, first, the creation of a situation in which one unit, the mixer, shall always control the volume of output and, second, the maintenance of this condition with the use of as little extra productive capacity as possible in other operations.

These conditions present a problem that is easy enough to define in general terms but which it is not as easy to solve, because the conditions that surround each job vary from day to day, making it necessary frequently to reanalyze the whole set-up. Most of the enterprises which are commonly referred to as manufacturing enterprises are largely conducted under roof in a permanently located plant. Concrete paving work is done out of doors, and the plant is shifting its location all the time. Therefore, while the problem which is involved in adjusting productive capacity throughout a series of operations is a more complicated one in other fields, once a series of operations is put into balance, the work accomplished is likely to be more permanent than it is in the paving field.

Value of Coordination.—To determine how much can reasonably be spent in order to make the mixer the key producer and to develop production to a point where it is in harmony with the productive capacity of the key producer, it is first necessary to know what losses are sustained by reason of any lower rate of production. The nature of these losses has been developed before, but it may be advisable to remark again that from every practical standpoint, as well as from every sound theoretical standpoint, if the mixer is being operated as the key producer, all of the job stops whenever the mixer stops. It is obvious that this statement applies to such operations as finishing, measuring batches, filling the hoppers, etc. It may not be as clear that it applies equally to subgrading and to form setting. Still the fact remains, for, at least to anyone who has ever assisted in the conduct of a paving job, it will be clear enough that grading, subgrading, form setting, and similar operations tend to keep the pace set by the mixer. There is no such thing as setting a steady pace in any of these operations and maintaining it without regard to production at the mixer. All subsidiary operations move ahead about as the mixer moves, and though they do not actually stop when the mixer stops, the letdown which takes place is clear enough when the work is studied over any extended period.

Value of Lost Time.—Another way of expressing this same idea is that if a mixer which has 48,000 batches of concrete to pour turns out 48 batches an hour, the work will be completed in 1,000 hours. If, however, it pours only 36 batches an hour, it will have to work 1,333⅓ hours, or more than a month longer than really is necessary. Now it will be perfectly obvious

that the batch-measuring device, the trucks, and the finishing machine will work as many hours as the mixer works. It will also be obvious that subgrading cannot be completed a month in advance of paving and that forms cannot be set a month in advance. As the key producer lags, the whole job lags. But the payroll remains pretty constant, because the number of men used is dictated more by the equipment and the methods than by the production. It will also be apparent that depreciation continues at a pretty constant rate, because a machine that is turning over at all in the dust of a construction job appears to wear out about as fast when it carries no load as when it is working under full load. The daily cost of operation does not, therefore, vary much, no matter how much production varies. This cost, exclusive of materials, as has been developed (see p. 41) is not far from $400 a day. This is a very general figure, but in the nature of the case it would serve no useful purpose to make it more specific. There are, in this country, rather wide regional differences in the wage scale. The amount and the value of the equipment used on different jobs differ a good deal. Fuel prices vary from place to place. Methods of operation also differ, and with these, there are unavoidable differences in the number of men employed. All of these matters influence the total daily cost of operation so that it may in any individual case vary a good deal from the general figure given here. This is not important, however, for the contractor who is analyzing his work in this way will, in any event, wish to use his own figures on cost, but the figure given will illustrate the points involved as well as any. The matter most important here is that this cost is not much influenced by the rate of production. Indeed, ordinarily it varies so little from this cause that it may properly be viewed as quite independent of the rate of production. In short, it takes on the aspects of a constant. But if the cost of operation is $400 a day, this is $40 an hour—10-hour working day basis—or 66⅔ cents a minute, or for ease of reference, let us say about 70 cents a minute. Dropping one batch an hour—10 batches or 12½ minutes of time a day—is, then, in fact, a loss to the contractor of some $8.75. Production at the rate of 40 batches an hour which is 400 batches a day involves the loss of 80 batches a day which is an actual loss to the contractor of about $70 a day. Production at the rate of 300 batches a day—the loss of 180 batches a day—represents a loss of $157.50, and production at

the rate of 200 batches a day, the loss of $245 a day. These figures are given to bring out the fact that low production is unavoidably expensive, unavoidably so, because even if the job is planned on a low-production basis, the losses here shown cannot, as a general condition, be much reduced. It may be added parenthetically that this also shows why the cost of arbitrary inspection is so high. Such inspection in a thousand ways interferes with production. Every order that interrupts production or slows it down increases cost. This is unavoidable.

High Cost of Securing High Production.—On the other hand, efforts to so adjust operation as to obtain high production at once bring into operation the law of diminishing return. In other words, as the full theoretical production is approached, the cost of the extra men and the extra equipment mounts more rapidly than production mounts, so that, in general, it will be found that under actual working conditions the most economical rate of production is a little under the maximum rate theoretically attainable.

To illustrate a little further, if production is averaging 330 batches a day, the contractor is losing about $130 a day through underproduction. During a fair working season, about 120 good working days, his loss from underproduction will, then, amount to about $15,000. This is a sum sufficiently large to justify a very considerable attention to securing better organization and, if necessary, adding equipment, if by this means he can bring production to a proper level. But if production is running 450 batches a day, the loss of some $26 a day or of about $3,000 during a fair working season, while justifying attention, will not be as easy to correct profitably, for the number of men and the amount of extra equipment which will be needed to force perfect production may cost as much or more than is saved by their use.

Indeed, it probably is true that perfect production at the mixer may be accepted as all but impossible of attainment because of conditions surrounding the operation of the mixer itself. To attain a perfect cycle and attain it every time, hour after hour, requires a perfection in time-measuring devices and in control that has not yet been applied in this work. The fact may, therefore, be accepted that production in excess of 46 batches an hour cannot be sustained over extended periods, though produc-

tion at the rate of 47 batches an hour has been secured over periods of some hours' duration.

Mixing Operations.—The operations which must be performed at the mixer in turning out a batch of concrete are as follows:

1. *Loading Skip.*—The skip must be loaded. This can be done while the previous charge is being mixed. Under the somewhat antiquated system which requires that the cement be brought to the job in sacks and there piled along the road, the operation of dumping the cement into the skip will sometimes take longer than mixing the batch. Of course, this method of

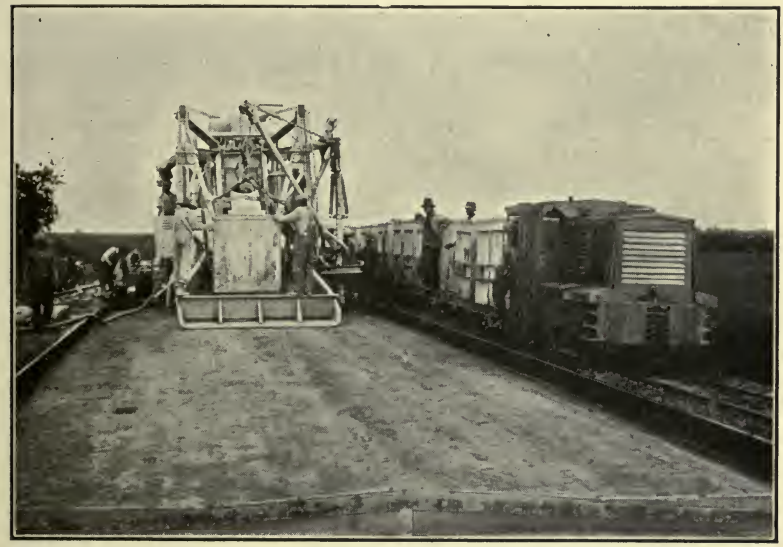


FIG. 61.—Charging the skip, a drag template in the foreground. Industrial railway delivery of material.

handling cement is as obsolete as are all other purely manual methods, but if it chances to be the method in vogue, men who are strong enough and active enough to do this work within the time available should be put onto this work. Ordinarily, however, handling the cement does not prevent charging the skip within the time available for this purpose, generally from 40 to 50 seconds (See Fig. 61).

2. *Raising Skip.*—The skip must be raised to a vertical position for the purpose of dumping the batch into the drum. On a modern mixer in reasonably good condition this operation takes from 9 to 10 seconds, during which period the material in

the skip is discharging into the mixer only during the last 1½ to 2 seconds.

3. *Discharging Skip.*—The material in the skip is never fully discharged when the skip reaches the vertical position and sets the timer. The better modern mixers sometimes discharge the skip in as little as 3 seconds after it is in vertical position, if the sand and coarse aggregate are dry; but under ordinary working conditions, they tend to require from 4 to 5 seconds, running a little over 5 seconds if the aggregate is wet enough to moisten the cement appreciably. As there are a number of standard pavers which, under ordinary working conditions, will regularly discharge within 5 seconds after the skip reaches a vertical position, this period is considered standard for the lag in charging as mixers are now designed.

4. *Mixing.*—The mix must be retained in the drum the full specification period, in most places, 60 seconds.

5. *Discharge Lag.*—Every mixer should have on it some device for timing. A timer which rings a bell at the completion of the mixing period is the best as well as the most generally used. When the bell rings, the operator must move the discharge lever and the discharge mechanism must open the discharge before the material appears in the discharge chute. These operations generate a lag, partly due to the fact that no human being reacts instantly to any ordinary stimulus and partly to the fact that it takes time for the mechanism to work. Generally 2 seconds is about the bottom limit for this lag, which is termed the discharge lag, but 3 seconds is a more ordinary average. Sometimes it runs as high as 4 seconds. The lag in discharge tends to offset the lag in charging but cannot reasonably be so treated if it is not a uniform lag. Thus, a lag which for successive batches is found to be 2.7, 3.2, 2.8, 3, 3.1, 3.3 seconds, etc. over long periods might reasonably be treated as a 3-second lag, though the amount by which this lag exceeds 2 seconds, though due entirely to a slow reaction on the part of the operator, is quite uniform; but a lag reading 1.9, 3, 2, 4.2, 2, 2.2, 5, 2.1, 4, 3.1 seconds, etc. would appropriately be treated as a 2-second lag, because the part chargeable to the operator is not uniform.

6. *The Discharge.*—The mix must be discharged. A wet mix can be quite thoroughly discharged from a good mixer in as little as 8 or 9 seconds, but there is no mixer now on the market which will make a complete discharge in less than 10 seconds, if

the consistency is such that it meets present requirements as to slump. Concrete having a slump of 1 inch or less flows slowly in the chute and piles up in the bucket.

7. *Dumping the Bucket.*—Finally, the batch must be deposited on the subgrade. As this should always be done while the next batch is being mixed, it does not affect the mixing cycle except on those jobs where the mixers are operated by utterly untrained men.

The Mixing Cycle.—The full-production mixing cycle with all specification requirements met may then be calculated as follows:

	Seconds
Specification mixing time	60
Lag in charging	5
Simultaneous raising of skip and discharging	10
Total	75

Stated in this manner there is, however, no recognition of the lags described above. It is, therefore, preferable to state the cycle as follows:

		Seconds
1. Specification mixing time		60
2. Lag in charging	5	
3. Less lag in discharge	2	
4. Net lag as affecting timer		3
Normal setting of timer		63
5. Lag in discharge		2
6. Simultaneous raising of skip and discharging		10
Total mixing cycle		75

Operating Difficulties.—The 75-second cycle is the minimum mixing cycle. From the production standpoint this is an important consideration. It is not customary to give any tolerance in the mixing. Therefore, the operator has no play whatever here. He must either make his batch in 75 seconds or he must make it in a little over 75 seconds, thereby losing a little time. He is not allowed to turn out the next batch in 73 seconds if the last one took 77 seconds. The result is that anything less than perfect operations tends to accumulate a noticeable loss of time during a full working day, and as the loss of just a shade less than 1½ seconds

per batch, when production is running close to the top limit, will cause the loss of a batch an hour, it will be apparent that the operator must be both steady and well trained if even larger losses than this are not continually to recur.

The Set of the Timer.—To add to the difficulty the timer on the mixer is not a very accurate instrument. Moreover, it is not adequately protected from the dust. Unless the timer is kept in first-class condition, well oiled and clean, it tends to drag. Both the superintendent and the inspector should watch this instrument with care, as it is essential to the contractor that the time interval be set correctly. It appears commonly to be the attitude of inspectors that, under no condition, can the time properly be set short. They are not as scrupulously attentive to seeing that it is not set long. The general theory seems to be that the state must not be robbed, but that gouging the contractor has many of the aspects of a virtue. The proper attitude is that the timer should be correcty set at all times, but owing to the fact that it is not adequately housed, this requires both constant and careful attention. It may be observed, though this is not the theory under which inspectors commonly work, that setting the timer really is a responsibility resting on the management. As a matter of fact, the inspector generally has no legal right to touch the timer, the water-regulating device, or any other adjustment on any machine on the job. He may properly require the adjustment of these or other devices when they are not correctly set, but this is a very different matter.

Time Control on Other Operations.—The timer is not a perfect instrument, but it provides a control over the mixing time which is better than can be had over the other operations which, being in many cases uncontrolled as to time, tend to absorb more than their proper quota of time. The only practical means of controlling the rest of the mixing cycle is to start the skip at the same time the discharge is started and close the discharge when the skip reaches its full vertical position. The time that is required in raising the skip is quite uniform at about 10 seconds, varying more with the engine speed than with the different makes of mixers; so it provides a pretty satisfactory control over these operations. It cannot, however, be used with all mixers, as there appear to be some which will not discharge a full batch of concrete of the consistency now generally used in paving work within the time that this method of operation allows.

Forcing the Discharge.—Most mixers dribble the discharge a little. Some dribble it a good deal. As a matter of fact none of the mixers now on the market can be depended on to discharge a full batch of proper consistency within 10 seconds unless the discharge is forced, that is, unless the discharge chute is arbitrarily closed at the end of 10 seconds, and the undischarged concrete carried over into the next batch. The amount which will be carried over is not large, and ordinarily a point is soon reached where a full batch is discharged during each discharge period. Thereafter the amount left in the drum remains quite constant. As this is remixed with a new batch every 1½ minutes or less, if production is at a high rate and within 2 minutes, even if operation is not being very well conducted, no harm can reasonably be ascribed to the practice as long as the drum is not overloaded. Occasionally, however, a mixer cannot be forced to discharge a full batch in 10 seconds, and in such cases the carry-over increases until the drum fails to hold both the carry-over and the next batch, and slopping results. When such a condition exists, either the interior of the drum is dirty, the blades or the discharge chute worn, or the blade design faulty. As long as any of these conditions persist, the practice cannot be followed with much advantage even if an occasional batch is split in order to empty the drum, for splitting batches is likely to absorb as much time as extending the cycle enough to obtain a full batch discharge each time.

Simultaneous Charging and Discharging.—Objection is sometimes raised to closing the discharge as the skip reaches full vertical position, on the ground that this method of operation momentarily overlaps charging and discharging. Stop-watch readings show that the skip begins to discharge into the drum about 2 seconds before it reaches vertical position. There is, therefore, a period of about 2 seconds during which charging and discharging do overlap under this system of operation. As the drum commonly revolves, however, at the rate of only about 15 revolutions a minute, 1 revolution every 4 seconds, it will be apparent that none of the new batch should carry up and over far enough to reach the discharge chute during this period. If it does, the drum is being run too fast, and as the contractor obtains no advantage from operating in this way, it is better for him to correct the trouble by reducing the drum speed than to adopt a longer mixing cycle.

Overlapping Operations.—High production on the part of the mixer itself necessarily requires the use of the lowest mixing cycle obtainable under existing specifications. This, in turn, requires that operations must be overlapped or, in other words, performed simultaneously in so far as this is possible. The minimum mixing cycle given above is based on the most complete overlapping of operations which is possible with the latest and most improved types of mixers. The skip is raised while the drum is discharging; the bucket is dumped while the next batch is being mixed, etc. The list could be extended but this is not necessary, as the point that fast operation and the greatest possible overlapping of operations are inseparable is perfectly clear.

Splitting Batches.—For this reason there are some practices in mixer operation which should be absolutely prohibited. Splitting batches is one of these. To split a batch unavoidably results in running out and dumping the first half while the balance is retained in the drum, thereby extending the mixing cycle. Commonly some 20 seconds are used in handling the first part of a split batch, an utterly useless waste of time.

Moving the Mixer.—The mixer should be moved just after it is charged. Any worth-while mixer has power enough to do this easily. If the material supply is snappy, the batch in the bucket can be run out and dumped before the move, but it is better to move before the batch is run out, as the trucks need as much time as possible for charging the skip. Under no circumstances should the operator be allowed to develop the practice of moving when the drum is empty. To do so subtracts the time spent in moving from the productive time and so reduces the daily output accordingly.

Standardizing the Move.—The distance moved each time should be standardized. If a five-bag batch is being mixed, it is good practice to move about 9 feet after each fourth batch is dumped, pouring at the end of the boom. For a six-bag batch, the move will be about 11 feet. This gives a clear space about equal to the length of the move next to the mixer where work can be done on the subgrade, but the necessity of operating in this fashion depends somewhat on the practices which govern the final finishing of the subgrade and on the amount of reinforcing steel that is being placed, etc.

Spreading the Concrete.—The accuracy with which the batches are spread is a matter of larger importance to contractors than

seems to be appreciated. Of course, the matter of most importance is production. That is essential to low cost, and no style of operating the mixer which interferes with high production should be permitted. Still the matter of proper spreading is important enough to justify the comment that the accuracy with which this work is done always affects the amount of work which the puddlers must perform and may even affect the number of men employed on this work, for with really good spreading the amount of material which must be rehandled by the puddlers is much reduced.

Value of Trained Men.—From this discussion it will be apparent that a good mixer operator is essential, if high production is to be secured. He is, indeed, one of the most important men on the job. Many contractors attempt to save money by putting untrained men onto important machines and allowing them to learn to operate these machines as best they can. The practice is bad enough when the contractor or his superintendent give personal attention to the training of such men, but when they are left to learn the matter of operation as best they can, the results often are astonishingly expensive. Indeed, it is no uncommon thing to find that self-trained operators with no other experience than that obtained on the job in hand are losing 10 per cent or more of the working day through sheer lack of knowledge of how properly to operate the mixer. Such men may and generally do work for from $10 to $20 a week less than a first-class operator would accept, but if production superintendents would realize that 10 per cent of the day is 60 minutes and that those 60 minutes probably represent $40 or more in direct and indirect cost of operation, the utter folly of endeavoring to save money by hiring cheap undertrained men to do important work would be apparent. High production requires real skill and real ability both in the management and on the part of the men. Efficiency is no accident. It is a matter of careful planning and often of gruelingly hard work, and men have to be well paid to develop it. The really important point, however, is that the contractor who tries to secure it on the basis of cheap labor and cheap superintendence is certain to find that the losses which these cheap men cause him in profits he fails to make amount to many times what he would have had to pay for the services of really high-class assistants.

Figure 7 gives the summary of a series of stop-watch readings on a mixer operated without proper attention to the training of the operator and without proper attention to the capacity of other elements in the production series. Figure 8 gives a similar summary after these matters had been adjusted. The importance of good operation probably can be brought out in no better way than by calling attention to the difference in production which resulted.

CHAPTER XIII

WATER IN MIXING AND CURING

Though it is not always thought of as such, the water used in mixing concrete really is as much one of the materials of construction as is sand or cement. Without it, concrete cannot be produced. But the water has other uses as well. More or less of it is used in cooling the mixer and other engines. It feeds the boilers if steam-driven equipment is used. On hot dry days a good deal is put onto the subgrade on the theory that this prevents the flow of water from the fresh concrete into the subgrade. Sometimes the subgrade is rather heavily wet down and rolled the night before the concrete is to be laid on it, and often, if low spots in the subgrade must be filled, a little water is used to assist in securing proper compaction. On most jobs, a large amount of water is used in curing the pavement.

Water Supply Must Be Adequate.—Not all of these requirements are equally important or equally insistent, but their recital serves to lay emphasis on the fact that a good deal of water is needed on every job and that the nature of these needs is such that, while the mixer no doubt makes the most important and the most insistent demand on the water supply, there are other demands which are of enough importance so that the work will be seriously handicapped if they cannot be met. The problem of the superintendent is to keep the job running at a high rate of efficiency. As has been pointed out in other places, this necessarily means that all parts of it must be coordinated which, so far as the water supply is concerned, means that it must be both adequate and dependable. As a matter of fact, a really adequate water supply is rarely found on concrete paving jobs, the general practice being to install a totally inadequate pipe line and thereafter to operate at pressures which cause leakage, distorted valves, and more or less breakage, in this way considerably lowering the dependability factor.

Outlets.—Only one system of delivering water is in common use. The water is pumped through a pipe line laid on the surface

of the ground along the right of way to any points at which it is to be used. Under the prevailing practice, and this practice is probably as satisfactory as any, provision is made at regular intervals, generally each 200 to 300 feet, for taking water from the pipe line. There are a number of styles of connections which may be made for this purpose, but the simplest is an ordinary T-coupling, the third opening in the T being closed with an ordinary plug. Where this form of outlet is used, there is some trouble in making a hose connection when there is any pressure on the line. As a result, some contractors close the outlet T with a short nipple and an ordinary ball valve. This practice is expensive and has not proved entirely satisfactory, because the high pressures used in these pipe lines tend to overstrain and so to ruin these valves. A better practice is to cap the short nipple which is used beyond the valve where this connection is in vogue and then open the valve, allowing the cap to carry the pressure. On the whole, however, the most practical method of handling the problem of outlets is originally to build the pipe line with plugged T's about every 300 feet and then, each night, in preparation for the next day's run, to replace the plugs with capped valves for such a distance as is likely to be covered by that day's run. If water is being used in curing the pavement, the saving by the above method does not amount to a great deal unless the water is pumped over 2 miles, but if chemicals are used in curing, the saving in the number of valves required is considerable.

To feed the mixer, a heavy hose is connected with one of these outlets. These connections are also used to obtain water for sprinkling and for any other job requirements, but when used for such purposes a reducer and a light hose are employed.

Lost Time.—A study of the "lost time" on a job commonly shows (see Figs. 7 and 8) that the time lost as a result of trouble with the water supply is rather a large item. Moreover, using the style of development applied to other phases of production management, the loss of 5 per cent of the working day through trouble with the water supply, not an uncommonly high loss, amounts to 30 minutes, worth $20 or more a day. There is, then, ample justification for an analysis of the methods and the equipment used on this work, for it is quite an essential that the water supply equipment shall be adequate as that any other part of the equipment shall be adequate. Probably from the engineer-

ing standpoint, it is more important, for, while production is adversely affected by current practices, quality may be almost as seriously affected.

Amount of Water Required.—Basically the water trouble on almost all concrete jobs arises from an effort to use an utterly inadequate pipe line. With full production, a batch of concrete is produced every 1¼ minutes. Few jobs, it is true, maintain this rate consistently over any extended period, but a good many reach it not infrequently for a few minutes at a time. This rate of production sets the rate of water delivery. About 15 seconds are required in discharging the measuring tank on the older mixers, though recent models discharge somewhat faster. A full minute is, therefore, all that can be allowed for the delivery of the water for a batch of concrete. As a matter of fact there often is less than a minute available for refilling the tank, because the operator fails to close the discharge and open the inlet valve. Some machines now open the water discharge automatically but there are a good many hand-operated water controls still in use. A 1-inch slump normally requires about 5 gallons of water per bag of cement, roughly 30 gallons per standard six-bag batch, of which about 20 to 25 ordinarily must be supplied from the water tank. Under the assumptions made above, this is equivalent to 25 gallons a minute. With full production and a 10-day curing period, it will be necessary continually to provide for curing at least 2 miles or rather over 20,000 square yards of paving. Rates of production as high as this are rare, even with the six-bag pavers, but rates of production which will require the constant care of at least 15,000 square yards of paving are not uncommon. To cure concrete properly requires that the earth covering shall be kept moist, not merely that it shall be wet down once in a while. This is a matter at present given far too little attention, for the strength of the concrete, particularly in hot weather, can be seriously reduced if it is not properly and adequately done. But the rates of evaporation from loose soil, such as that used for covering the pavement during the curing period, are high. In fact, the evaporation from such a soil covering, when the temperature is high, the humidity low, and a brisk breeze is blowing, typical summer conditions over the greater part of the United States, will often exceed ⅓ inch per day and may even exceed ½ inch, equivalent to from 2 to 3 gallons of water per square yard of pavement.

These are, of course, the highest rates of evaporation likely to be met, but they must be met if the pavement really is to be moist cured. It is at just these times, moreover, that full protection of the pavement is most required, for it is at such times that the air would draw enough moisture out of a green concrete seriously to injure it to the greatest depth, if adequate protection is not given it. These rates of evaporation, therefore, must be met if the pavement is to be fully protected and must govern the available water supply.

Water Needed for Curing.—Finally, contractors properly prefer to conduct all their operations simultaneously. For that reason, though night sprinkling may, at times, be practiced, the contractor generally desires to attend to it during the day, as the work is then under the observation of his regular foremen. The inspector also has a better grasp on the situation if it is done at that time, and, of course, during very dry weather a night wetting is not sufficient to keep the pavement moist throughout the following day. It is, therefore, proper to view the pavement-curing problem as one which under full production may involve the daily delivery of from 40,000 to 60,000 gallons of water in addition to mixer requirements and, even under current normal production standards, the daily delivery of from 30,000 to 40,000 gallons of water in excess of mixer requirements.

Pump Capacity.—As shown above, full production at the mixer requires for mixing the concrete a somewhat variable amount not ordinarily exceeding 10,000 gallons per day. To this amount there must be added a somewhat variable amount for wetting down the subgrade, for supplying machinery, and for other miscellaneous purposes. It is, therefore, apparent that, while a pump capable of delivering 100 gallons per minute has sufficient capacity to meet all of the needs which will ordinarily arise until the production of 18-foot pavement exceeds 750 feet a day, it may, at times, prove not wholly adequate if more than this amount of pavement is being regularly produced, unless some of the work on curing and on wetting the subgrade is done at night.

One thing, however, must be emphasized, namely, that the adequacy or the inadequacy of a pumping plant of the size indicated depends entirely on the size of a pipe line installed and the distance the water must be pumped. The pressure head which will be developed in delivering the required amount of

water must always be within the limits for which the pump is designed. There are vital differences between a pump designed to deliver 100 gallons a minute against a pressure head of 100 pounds and one designed to deliver at the same rate against a pressure head of 400 pounds.

Pressure Heads.—This raises the question as to what pressure head is required in delivering water. Table VIII gives the pressure head in pounds for various rates of delivery in gallons per minute per mile for three sizes of common iron pipe such as is generally used on paving jobs and is believed to yield accurate results as long as the pipe is in fair condition. As the pipe, however, becomes somewhat battered, twisted, and rusty with use, the pressure head required to force water through it will increase so that, in a general way, the figures given are minimum figures, which may be exceeded somewhat after the pipe has been in use a few years.

Cause of Inadequate Water Supply.—The pressures given in the table are the number of pounds, as read on the gage at the pump, which will be required to deliver the stated number of gallons per minute at the outflow end of a pipe line 1 mile long. Thus, if 50 gallons per minute are required and a 2-inch pipe 1 mile long is to be used, the gage at the pump must be run up to 227 pounds. If 100 gallons are desired 1 mile from the pump and a 2-inch line is used, the gage pressure at the pump must be run up to 820 pounds, and if a delivery of 100 gallons a minute is required 3 miles from the pump, the gage pressure would have to be run up to the astonishing amount of 2,400 pounds. Of course, neither ordinary pipe nor ordinary pumps will stand any such pressures. The point it is desired to make is that right here is the explanation of the poor water supply and of most of the lack of dependability in pumping plants as installed on paving jobs today. The impossible is being attempted. A really adequate water supply simply cannot be driven through a 2-inch pipe 2 or 3 miles long. Indeed even a supply that really is adequate only for the paver is likely to cause a pumping pressure of well over 200 pounds if it has to be pumped 3 miles. The remedy lies in using a larger pipe; for 100 gallons of water per minute can be driven through nearly 2 miles of 3-inch pipe with the same gage pressure at the pumps, *i.e.*, the same effort on the part of the pump, which is required to drive it ¼ mile through a 2-inch pipe. Put bluntly, there is no place on the modern paving job for the

TABLE VIII.—PRESSURE REQUIRED AT PUMP FOR EACH MILE OF PIPE LINE TO SECURE DESIRED DISCHARGE THROUGH 2-, 2½-, AND 3-INCH ORDINARY IRON PIPE[1]

Diameter of pipe, inches	Number of gallons to be pumped per minute, or per 10-hour day													
	20	25	30	35	40	45	50	60	70	80	90	100	110	120
	12,000	15,000	18,000	21,000	24,000	27,000	30,000	36,000	42,000	48,000	54,000	60,000	66,000	72,000
	Pressure required at pump, pounds per square inch													
2	42	62	88	117	151	188	227	318	421	543	673	820	982	1,145
2½	14	21	30	39	50	62	76	106	142	181	224	275	330	385
3	6	9	12	16	21	26	32	44	59	75	93	114	137	161

[1] Based on Williams and Hazen's hydraulic tables.

NOTE: To obtain the total pressure against which the pump must work, multiply the figures given in the table beneath the desired gallons per minute and opposite the desired diameter of pipe by the total length of the pipe line in miles and then add to this product the figures obtained by multiplying the difference in elevation between the pump and the discharge end of the pipe by 0.434.

now generally used 2-inch water supply line. Contractors putting in new pipe line should consider nothing less than a 3-inch line.

Other Reasons for Using 3-inch Pipe.—With no other consideration than the water supply for the mixer, contractors could still well afford to use 3-inch pipe, for its use would result in a water delivery at a pressure far less destructive of pumps, hose, mixer valves, etc. than the pressures required in working through 2-inch pipe. Moreover, the added cost of pumping enough water for adequate curing and for properly sprinkling the subgrade would then be so slight that the problem would cease to be troublesome, and there would be much less tendency to ask permission to use chemicals as curing agents. The cost of 3-inch pipe is about twice that of 2-inch pipe. Installing it also costs about twice as much per mile laid. The direct cost of the change to the larger size is not, therefore, excessive, and as suggested above, delays due to a poor water supply, broken pump parts, burst hose, etc. would be of such reduced importance as more than to offset the extra outlay.

Proper Pump-operating Practices.—With the installation of 3-inch pipe, relief valves should be installed to protect the pumps, the pipe line, the hose, and the mixer valves against excessive pressure. Gages should also be installed at the pump, and instead of permitting the pumps to run wide open, their speed should be controlled according to the rate of delivery desired and the distance this delivery must be pumped. Thus, as an illustration, if the maximum water requirement is 60 gallons per minute through 3 miles of 3-inch pipe line, the pumping engine should be cut down to a speed which will produce a pressure of about 150 pounds when making this delivery. The relief valve at the pump should then be set at slightly above this pressure, while the relief valve at the mixer should be set at 50 pounds or even less. This practice saves wear and tear on the pump and tends to avoid the breakdowns which always occur more frequently when machines operate close to or above the rated capacity than when they are operated at moderate loads.

Time Losses Due to Changing Hose.—In the total time lost on paving jobs because of water trouble, one of the larger items is that occasioned by changing hose. It is the general practice among contractors to set outlets in the pipe line at intervals of from 250 to 350 feet. As the mixer moves along, the hose which

is used to connect the mixer and the pipe line has from time to time to be detached from one of these outlets and moved to the next. The hose used is heavy; in fact, to move it four or five men often are required, and as it is stiff and hard to handle, both disconnecting it from its last connection and attaching it to the next are operations which require some time. Indeed, all things considered, it is not surprising that investigation shows that moving the hose commonly takes from 5 to 15 minutes with an average consumption of time approaching 10 minutes. With outlets installed from 250 to 300 feet apart and production at a normal rate, the hose must be moved two or three times every day with a resulting time loss amounting quite often to from 15 to 30 minutes a day, for the mixer naturally cannot work while the water supply is cut off.

The Value of Time Lost.—The value of time lost has been shown to be about 70 cents a minute. The losses which a contractor takes through the methods now in vogue in handling hose will, therefore, often exceed $15 a day, occasionally running under this but more often running higher, particularly if production is well maintained. As, when the season's work runs over 100 days, the direct loss due to the time spent on changing hose connections may easily exceed $1,500, the importance of this seemingly trifling detail will be apparent.

The Double Hose Connection.—To avoid this loss a double valve connection has been worked out and is now regularly installed on some types of mixers. The connection is simple, and if the mixer was not originally so equipped, the deficiency can be readily corrected in the field. To do so the regular hose connection is removed and a standard T substituted. To this two standard 45-degree fittings are attached by means of short nipples. Short nipples are then run into the angle fittings and valves are connected to the branches of the Y thus formed. An ordinary hose connection is then placed on each branch, completing the assembly. An extra hose of the proper length, depending on the distance between outlets and the location of the pipe line, must also be provided.

Operating with Double Hose Connection.—In operating, the first hose is connected to a regular outlet and to the mixer. At a convenient time the second length of hose is moved to the next outlet and connected. As the mixer nears the end of the distance that can be reached from the first hose, the second hose is con-

nected and the valves in the new line opened. As soon, thereafter, as may be convenient, the valves in the now dead line are closed, and it is disconnected at the mixer, after which it can be moved to the next outlet at a convenient time, connected up, and left ready for reattachment to the mixer at the proper moment.

In practice it has been found that this system of handling the hose connection will totally eliminate the loss of mixer time chargeable to changing hose if the foreman will give this matter a little thought and attention. The extra investment in hose and connection is therefore fully justified by the savings in time that may be reasonably expected to result from its proper use.

CHAPTER XIV

FINISHING AND CURING

Only a few years ago the finishing of concrete roads was entirely a manual operation. Indeed, it is still conducted in this fashion in some parts of the country, but the more common practice now is to do a large part of the finishing by machine, and there are a good many states in which the prevailing specifications practically require the use of such a machine. The introduction of machine finishers has not, however, entirely eliminated hand work, though some of the better finishers are constructed with this end in view and, in fact, appear to produce the best results when no hand finishing is done. Thus the problem which the job superintendent faces is one of obtaining an arrangement of machine work and hand work which, while preserving quality, will be fast and accurate and at the same time reduce the number of men employed as far as possible.

Objectives in Finishing.—The matter of quality in finishing involves directly two things, smoothness and accuracy. Perhaps it would be well to add that finishing operations ought to preserve, if not indeed to improve, the general quality of the concrete of which the slab is composed. They ought, moreover, to be such as to facilitate the use of a generally high quality of concrete rather than such as more or less definitely to interfere with the use of what is commonly admitted to be high-quality concrete. There are, then, a number of factors which must be considered in selecting the finishing methods to be used.

The Value of Smoothness.—The prevalent desire for smoothness in surface finish rests on two things, the personal comfort of those who use the completed pavement and the safety of the pavement itself. Either is an adequate justification for scrupulous attention to the finish. It is quite undesirable to reduce the pleasure to be derived from the use of expensive highways. It is equally undesirable to build into these highways such roughness as inevitably to cause their early destruction if they are subjected to heavy traffic. Roughness causes impact, particularly

where heavy loads are carried, and impact in turn tends to break up the pavement. The elimination of all roughness is, therefore, a matter of great importance both because the comfort of the public is at stake and because the life of the pavement may thus be favorably affected.

The Nature of Smoothness.—Smoothness is measured longitudinally along the pavement, variations from the correct gradient of ¼ inch in 10 feet being, under customary specifications, permissible. An angle, often overlooked, is that smoothness is not, in fact, as much affected by the amount of the variation from exact gradient along the pavement as it is by the rate of the change in gradient. To illustrate, the long undulating variations from exact gradient which are produced in some types of road surfaces by heavy rolling cause no unpleasant impression of roughness and little impact even though the amount by which these undulations vary from the exact gradient is considerably greater than would be permitted on a concrete pavement. This arises from the fact that by the very nature of the process by which they are formed, sudden changes in the actual surface gradient are avoided. The natural, as well as the correct, conclusion from this is that a satisfactory process for finishing concrete roads will not only be as accurate as it is possible to make it but will, from its very nature, preclude too sudden changes in the actual longitudinal gradient.

The Preservation of Structural Adequacy.—The finished pavement must be viewed as a structure. It is, therefore, as necessary that its structural adequacy shall be preserved as that the quality of the material of which it is composed shall be protected. But structural adequacy is attacked directly whenever construction methods produce areas of finished pavement thinner than the design contemplates. On the other hand, areas which are thicker than is required absorb concrete without yielding any particular benefit. In view of these facts, it may be well to note that the transverse distortion of the pavement which results from an ill-advised selection of finishing methods may be a good deal greater than commonly is supposed. Graphs in Figs. 64 and 65 show typical cases. In these cases the distortion of the surface exceeds ½ inch after allowing for form settlement. The purpose of the management in dealing with this phase of the finishing problem should be to select practices in finishing which yield the closest conformity with the design. Exact conformity

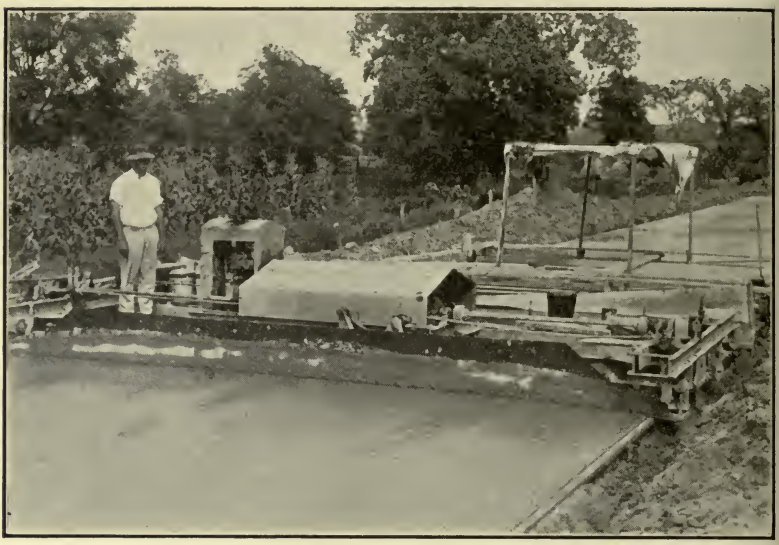


FIG. 62.—The double-screed finishing machine.

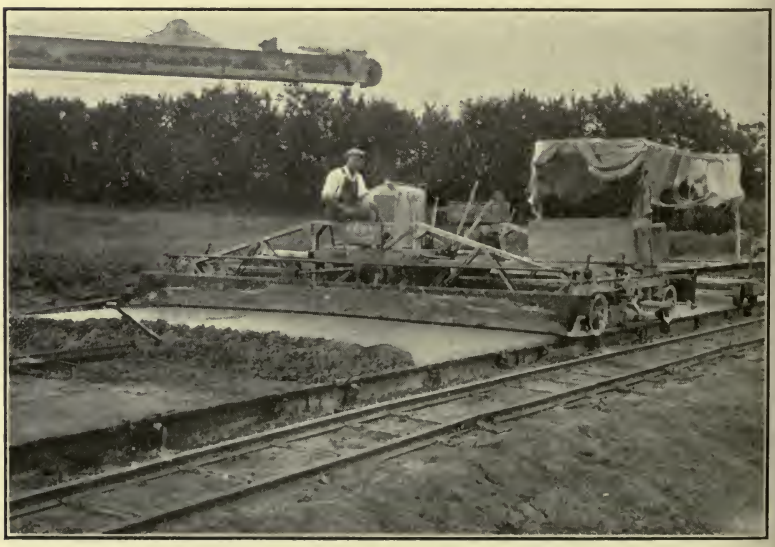


FIG. 63.—The combined tamp and single-screed finishing machine.

at all times is impossible, but a consistently close approximation can be had.

The above are the aspects of the finishing problem most in mind at the present moment: smoothness because of its effect on comfort, and accuracy because of its effect on the thickness of the pavement. There is an increasing demand that pavements be at least as thick as the plans require. From the structural standpoint this demand is reasonable enough, though, as has been pointed out in another place in this discussion, it does not, as at present expressed, give proper consideration to the element of tolerance. But as many of the widely used practices in finishing cause frequently recurring transverse distortions amounting to from ¼ to over ½ inch, the fact that the thickness of the pavement is receiving increased attention makes it doubly important that the management give careful attention both to the machines and the methods used in finishing, for these are an outstanding cause of thin pavement.

Other Essentials in Finishing.—Beside the matter of smoothness and the matter of accuracy, it is essential that the finishing methods selected involve no operations that are likely to reduce the strength of any element in the pavement. It is also essential that they be such that concrete of the highest quality can be used. The latter of these two requirements rules out any finishing method not adapted to handling relatively dry concrete, for it is generally conceded that a low water content and a high quality go together. The first rules out all systems of finishing which involve numerous reworkings of the surface, for these tend so to extend the finishing time that it overlaps the period within which initial set takes place, and in this way to reduce the strength of the pavement at least at the surface. Long working also tends to bring an undue proportion of any light material which may be contained in the mix to the surface. Scaling is one of the results of the use of such methods. A pitted surface is another.

The Double Sliding Screed.—The simplest, the cheapest, and at the same time the most consistently high-grade finish which has yet been developed is that produced by the double sliding screed. (Fig. 62.) To obtain the best results from this machine the concrete must be mixed relatively dry, that is, to a slump of about 1 inch. Recently conducted field tests indicate that with good mixing and a satisfactory grading of materials, a 1-inch slump can

be had with about 5 gallons of water per sack of cement, which low water content when coupled with a careful selection and propor-

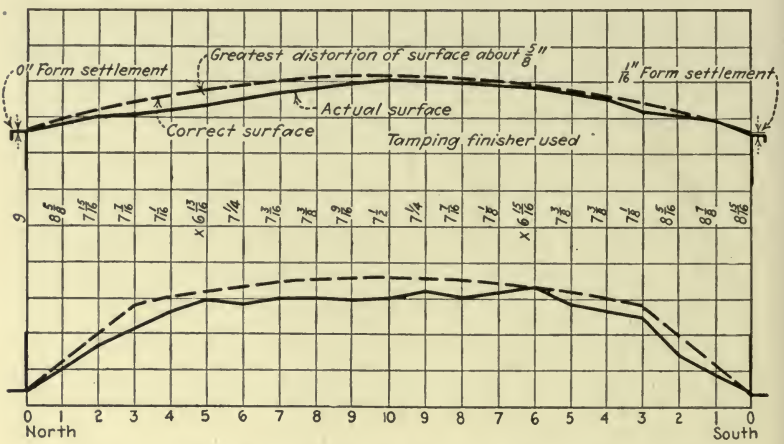

0" Form settlement
Greatest distortion of surface about 5/8"
1/16" Form settlement
Actual surface
Correct surface
Tamping finisher used
9
0 1 2 3 4 5 6 7 8 9 10 9 8 7 6 5 4 3 2 1 0
North
South

FIG. 64.—The effect of a distorted surface on pavement thickness.
– – – Cross section as designed.
— Cross section secured.
x, thin spots in pavement due to distortion of surface in finishing.

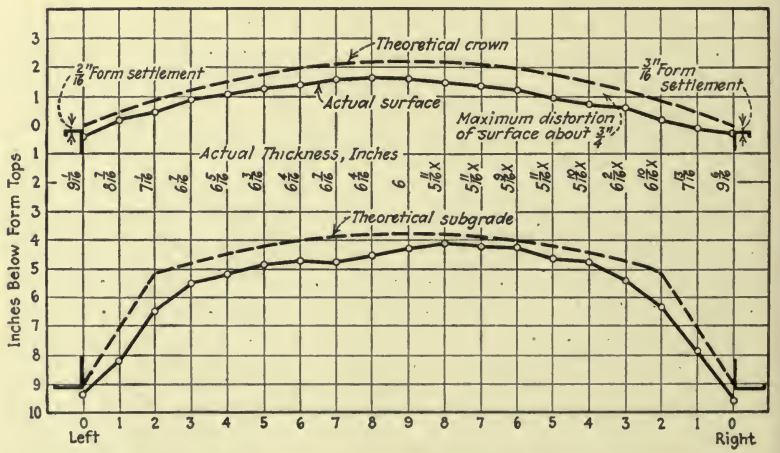

Theoretical crown
2 1/16" Form settlement
3/16" Form settlement
Actual surface
Maximum distortion of surface about 3/4"
Actual Thickness, Inches
Theoretical subgrade
Inches Below Form Tops
0 1 2 3 4 5 6 7 8 9 8 7 6 5 4 3 2 1 0
Left
Right

FIG. 65.—The effect of poor surface finish on pavement thickness.
– – – Cross section as designed.
— Cross section secured base.
x, pavement thin because of distortion on surface in finishing.

tioning of materials can be made to yield concrete having a crushing strength consistently above 4,000 pounds per square inch.

The Slump to Be Used.—It may be observed in this connection that, while the double sliding screed will handle mixes which have a slump that is a good deal higher than 1 inch, it is not in the contractor's interest to attempt to use wetter mixes. Wet mixes flow badly on the hills. They even settle out of shape on perfectly level ground. Often they are so lacking in body that a finish is impossible until settlement has taken place and perhaps even until the mass has begun to set. The use of wet concrete is, then, of no advantage whatever to the contractor. As a matter

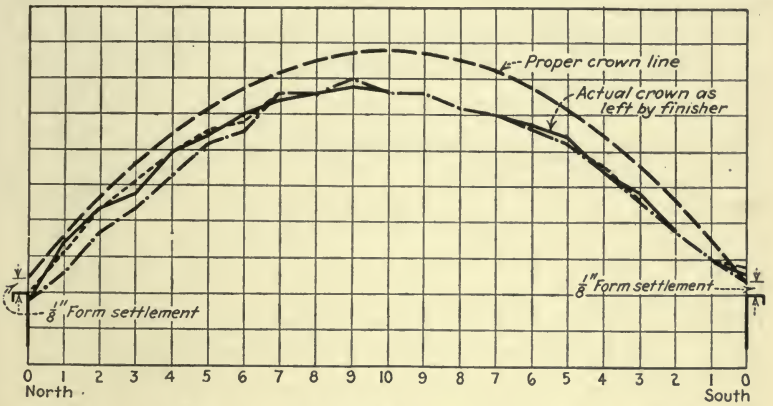

Proper crown line
Actual crown as left by finisher
1/8" Form settlement
1/8" Form settlement
0 1 2 3 4 5 6 7 8 9 10 9 8 7 6 5 4 3 2 1 0
North
South

FIG. 66.—The effect of hand finishing and wet concrete on pavement surface. Short dash line shows concrete as left by belt. Dot and dash line as measured twenty-four hours later. Note shrinkage on left side due to the use of a wet batch here.

of fact, its use is a positive disadvantage to him, for it cannot be held to correct cross-section, and as a result there must be a constant building up of low areas back of the finishing machine wherever it is used. This, of course, takes more or less labor but, though smoothness is preserved by this building-up process, it does not always correct the transverse distortion which is so much of a factor in producing thin pavement. The contractor should therefore most carefully avoid wet mixes. (See Figs. 66 and 68.)

Why Dry Concrete is Best.—Returning to the positive side of this question, dry concrete (about 1-inch slump) has enough body when first placed so that it will hold whatever crown is formed. The sliding finisher is a heavy machine, and as it works along over the surface, the gentle kneading motion which this weight and the motion of the screeds produce causes the concrete

to settle into a thoroughly compacted mass. Given, then, to start with, a reasonably dry mix and a uniform consistency as between batches, the surface which is left by the sliding-screed finishers is not only relatively accurate as to shape but, because of the "body" of the concrete underlying the surface, one that is not easily distorted.

Smoothness Easily Secured.—Another matter of importance is that the steady forward motion of this machine and the relatively slow even sliding motion of the screeds which themselves are relatively wide combine to produce a treatment of the surface which makes sudden changes from the exact longitudinal gradient of the pavement practically impossible. Form settlement may

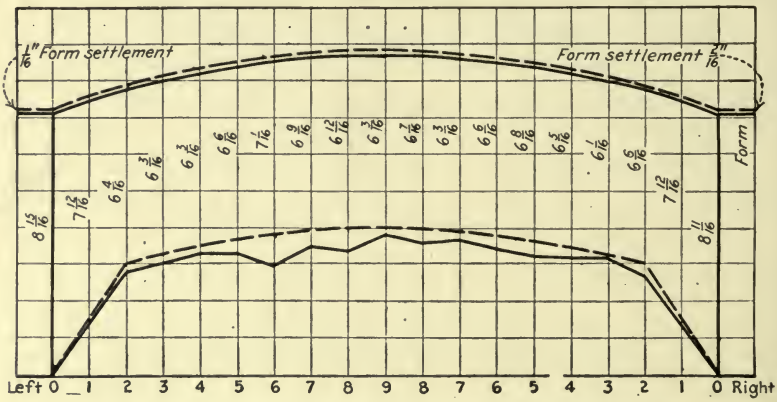


FIG. 67.—A typical surface as left by the double screed finisher.
Figures give pavement thickness at one foot intervals.

introduce undesirable changes in gradient, and careless setting of the forms can produce the same result, but the work of the machine itself is free from them. Where the forms are solidly placed and carefully checked, it is, therefore, a rare thing to find that low spots or other surface irregularities must be corrected where one of these machines is in use, unless there is considerable irregularity in the consistency of the batches used. The surface is, in short, not only correct transversely (see Fig. 67) but has a very high degree of accuracy longitudinally (see Table IX).

Method of Operation.—The double-screed machine should be run over the concrete at least twice. At its first passage it should push ahead of itself a considerable amount of concrete. On the second passage, there always should be some concrete in front of the plow, but the amount should not be as great as during the

TABLE IX.—VERTICAL VARIATIONS IN SURFACE OF CONCRETE PAVEMENT FINISHED WITH DOUBLE-SCREED TYPE OF FINISHER[1]

	Distance from center of slab in feet																		
Longitudinal distance	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9
Standard	30	25	21	17	14	11	9	8	7	6	7	8	9	11	14	17	21	25	30
Feet																			
1	29	26	22	20	16	13	11	9	8	8	9	10	12	14	16	20	24	27	30
2	29	26	22	20	16	14	12	10	9	8	9	10	12	14	16	20	23	27	30
3	30	26	22	20	16	14	12	10	9	8	9	10	12	14	17	20	23	27	30
4	29	26	22	20	16	14	12	10	9	8	9	10	12	14	17	20	23	27	31
5	30	26	23	20	16	14	12	10	9	8	9	10	12	14	17	19	23	27	30
6	30	26	23	20	17	14	12	10	9	8	9	10	12	14	17	20	23	27	30
7	30	27	23	20	17	14	12	10	9	8	9	10	12	14	17	20	23	27	30
8	31	27	23	20	17	14	12	10	9	8	9	10	12	15	18	21	25	28	30
9	31	27	23	20	17	14	12	10	9	8	9	10	12	15	18	20	24	27	31
10	32	26	24	20	16	14	12	10	9	9	9	10	12	15	18	19	24	26	30
11	30	26	23	20	16	13	11	10	9	8	8	10	12	15	17	20	23	26	29
12	30	26	22	19	17	13	11	10	9	8	8	9	12	15	17	19	23	27	28
13	30	26	22	19	16	14	11	9	9	8	8	10	12	14	17	20	23	26	30
14	30	26	23	20	17	14	12	10	9	8	9	10	12	14	17	20	22	27	30
15	30	26	24	20	17	14	12	10	8	8	8	9	12	13	17	20	24	27	29
16	30	26	23	19	16	13	11	10	9	8	9	10	12	13	17	20	23	27	30
17	31	27	24	20	17	14	12	10	10	9	9	10	12	14	17	20	24	27	30
18	30	26	24	19	16	13	10	9	9	8	9	10	12	14	18	20	24	27	31
19	29	27	23	19	16	13	11	10	8	8	8	9	12	13	18	21	23	27	32
20	30	26	23	19	16	14	11	10	9	9	8	10	12	14	18	20	23	27	33
Average	30.0	26.2	22.9	19.7	16.4	13.7	11.5	9.8	8.9	8.1	8.7	9.8	12	14.1	17.2	19.9	23.3	26.9	33.2

[1] All measurements in sixteenths of an inch from a plane $1\frac{1}{16}$ inches above tops of forms.

first passage of the machine. The facility with which this machine carries large masses of concrete ahead as it moves along the forms is one of its attractive features. Indeed, if the mixer operator is at all skilled in distributing the concrete as he dumps it on the subgrade, this machine can handle it with almost no further manipulation by the puddlers, who can, for that reason, be reduced to two men.

To wipe out the surface markings left by the screeds and to meet ordinary requirements as to final appearance, it is customary to require that the finishing machine shall be followed by a man with a long-handled float. To remove the marks left by the finishing machine satisfactorily, the float should be pushed out from the forms to the crown and then pulled back to the forms. One such treatment of an area is all that is required. If a subsequent belting is required, as it commonly is, the finishing-machine operator and the finisher can pull the belt whenever a 50-foot strip of pavement has been prepared for belting. As a matter of fact, the use of the long-handled float is not necessary and on the whole tends more to injure than to improve the finish. Finishers of this style are provided with a belt, and if this is used on the second run with a third run for belting (generally with the back screed down), a more correct finish results than when longitudinal floating is required. Whichever style of final finishing is used, this general method is economical as well as accurate.

Rapidity of Finish.—This discussion would not be complete without reference to the fact that the very limited re-treatment of the surface back of the finishing machine which is permissible when double-screed finishers are used leaves a soundness of surface not by any means always attained in this work. There are two reasons for this. In the first place, every manipulation of the surface disturbs it and hinders the proper setting of the concrete. Often a number of manipulations are called for, as transverse floating, longitudinal floating, rolling, dragging a rubber hose over the surface, one, sometimes two, beltings, etc. Each of these operations takes time. If the concrete was a little wet initially, it often is an hour or more before the last of these operations is performed. If the weather is hot and dry, the surface may require retempering before the last of them can be performed. All such re-treatments, of course, tend to bring light material, laitance, etc., to the surface as well as to break up the early set. In the second place, unless the water content in the mix is at

the lowest limit at which workability can be had, any tamping of the concrete, as where tamping finishers are used, brings an excess of water to the surface. In most of the modern mixes used in highway paving work, there is an excess of mortar, and severe tamping naturally causes some of this to come to the surface. The result is apt to be a mortar containing a considerable excess of water. As this mortar becomes the top of the pavement, the combined result of the delayed finish and the excessive water content in the mortar of which the top is composed is a dead appearance which all too loudly proclaims the actual effect of these factors. For the contractor, then, there is more than economy at stake in the use of a finishing machine which makes it possible to complete the finish rapidly and with a minimum of segregation in the materials of which the pavement is composed. As a matter of fact, where double-screed machines are being used to finish concrete of proper consistency (about 1-inch slump), the finish is so fast that the final belting can be, and in fact on fast jobs often is, done within 15 minutes after the concrete is poured, and so little segregation of materials takes place that the contractor's principal worry is to get enough mortar to finish with.

The Cause of Checking.—Another matter worth noting is that at least a large part of the hair checking on concrete pavements is due to the presence on the surface of relatively deep films of overwet mortar. As the excess of moisture dries out, the mortar shrinks and cracks. This is not the sole cause of checking, to be sure, but there are many occasions when the sole cause of checking is an excessive water content in the mortar brought to the surface by some one of the finishing processes.

Structure of Surface.—Finally, it ought to be remarked that the gentle kneading given by the double-screed machines while producing dense concrete does this without displacing any element in the mix. The fact that mortar is not brought to the surface in large quantities has been mentioned. Neither are soft stones, shale, coal, or other light pieces in the mix displaced and forced to the surface. With the finishers of this type the surface, therefore, is not apt to be composed of overwet mortar and the poorest elements in the mix. This is a matter of real importance, at least where the aggregate commonly contains an unavoidable percentage of undesirable material. From the engineering standpoint, as the surface takes the wear, it ought to be the toughest

part of the pavement. It cannot be made so under any process now in vogue, but it can be kept from being conspicuously the poorest part of the pavement, and the use of the double-screed finishing machine is the best approach to the desired end so far developed, for, while it does not produce a surface which is better than the rest of the pavement, it will, under ordinary working conditions, produce a surface that is not conspicuously of lower quality than the body of the pavement.

Single-screed Finishers.—Beside the double-screed finishers there are a number of tamping finishers which do excellent work. There is also at least one finishing machine which combines tamping and screeding. It has been the writer's observation that a single-screed machine, whether with or without a tamping device, presents some rather unfortunate aspects, the most conspicuous of which is its tendency to rock the forms. The very idea of the sliding screed is that a good deal of weight is thrown onto it, this being necessary in order to produce the kneading effect on which its effectiveness depends. Naturally, some of this weight must be carried on the forms, for the screed rests on them. With the double-screed machine, as the two screeds move in opposite directions, the thrust on the forms always is at least approximately in balance so that the forms are not disturbed. With the single-screed machines, however, the thrust is unbalanced; thus when the screed moves, for instance, to the right, the friction between the screed and the form tends to push the right form out. The flanges on the wheels keep the form from being pushed far out of line, but as form setting within 1 inch of exact width is unusual, some excess width between flanges ordinarily is provided so some rocking almost always takes place. If the subgrade is sandy, or wet, or composed of moist, plastic clay, a good deal of trouble may result from this rocking of the forms. On the other hand, while the single-screed machine is relatively light, the surface it secures is accurate and in general has the same characteristics shown in Fig. 67.

The Combined Tamping and Single-screed Finishers.—The combined tamping and screed machines (Fig. 63), as found at work in the field, produce an accuracy of finish which is better than that generally secured where the straight tamping machines are used, though it appears to lack a little of the uniformity of finish which the double-screed machines attain (Fig. 69). This is not a necessary result, as these machines can be made to do as accurate work

as any machine built, but rather seems to indicate that the care required in order to secure perfect results is somewhat greater than commonly is given to this work. The problem, from the

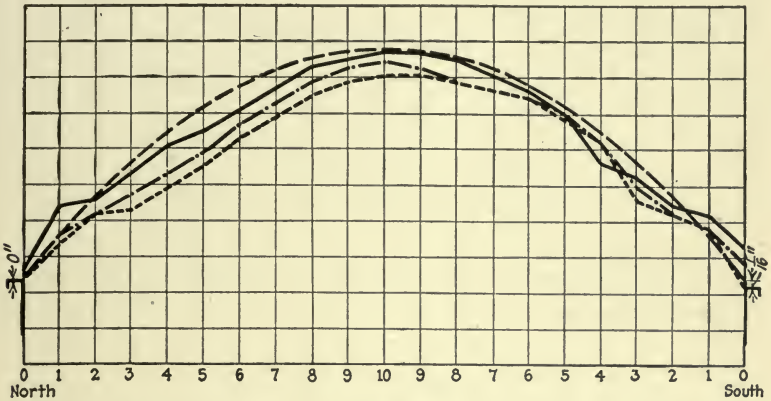


FIG. 68.—The effect of hand finishing and wet concrete on the pavement surface.

Dashed line is position final surface should have had. Solid line is position of surface as left by finisher. Dash and dot line is position of surface as left by belt. Short dash line is surface after concrete had set 24 hours. Note settlement on left side due to use of wet concrete here.

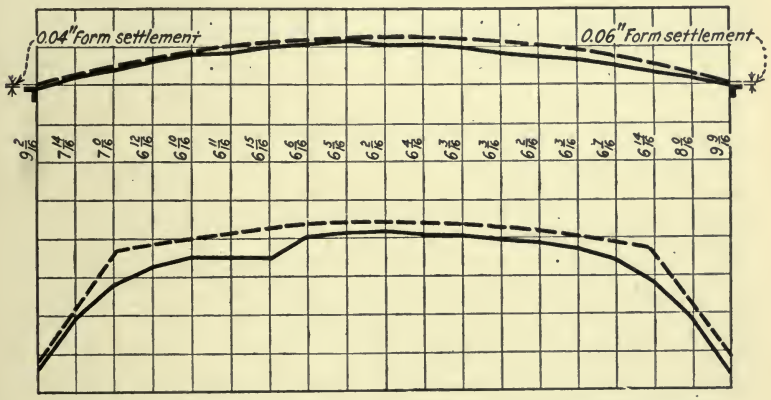


FIG. 69.—Surface secured by the use of a tamp and screed finisher.

– – – Cross section as designed.
— Cross section secured.

contractor's standpoint, is one of obtaining high-class results even when low-class labor is used. He cannot always obtain high-class labor even if he desires to do so.

These machines like the double-screed machines give the best results when allowed to belt their own work. No hand finishing should be required back of them. If the puddling is carefully done and the batches are of uniform consistency, a very satisfactory finish results.

Tamping Finishers.—The straight tamping machines can do good work but require considerable skill in puddling and in finishing the surface they leave (see Figs. 70 to 72). For the best work with these machines as with the sliding-screed machines, a dry mix (slump about 1 inch) is desirable. These machines require more careful attention and closer inspection, as well as, in

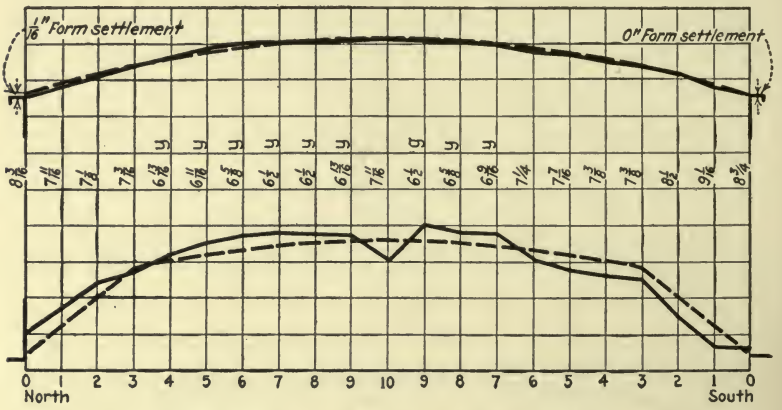


FIG. 70.—Good work with a tamping finisher.
– – – Cross section as designed.
— Cross section secured.
y, pavement thin because of high subgrade.

general, the expenditure of more labor both on puddling and on finishing, than are required where screed machines are used. The tamping finishers are relatively light machines so that they will not shove a large amount of concrete ahead. The concrete must, therefore, be spread with some care. Moreover, as careful measurements show that the thickness of the pavement can be reduced from ¼ to as much as ½ inch merely by a careless filling of the forms ahead of finishing machines of this type and the failure to carry a proper amount of material on the plow, no extended argument is needed to support the statement that under ordinary working conditions, low areas which are due to careless puddling ahead of the machine and inattention to the matter of keeping enough material on the plow are likely to be of

rather frequent occurrence. Indeed observations on numerous construction jobs indicate that this is a usual condition. This,

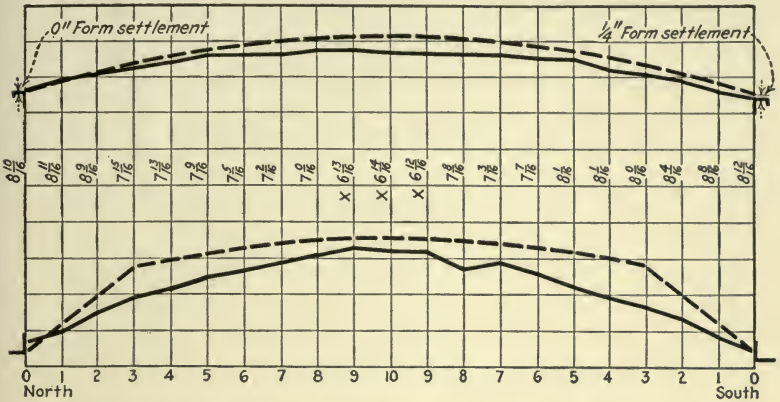


FIG. 71.—A poor surface as procured where the tamping finisher is used. x, pavement thin due to inaccurate finishing. Figures give pavement thickness at one foot intervals.

in turn, requires the use of additional labor on re-treatment after the work of the finishing machine has been completed and in

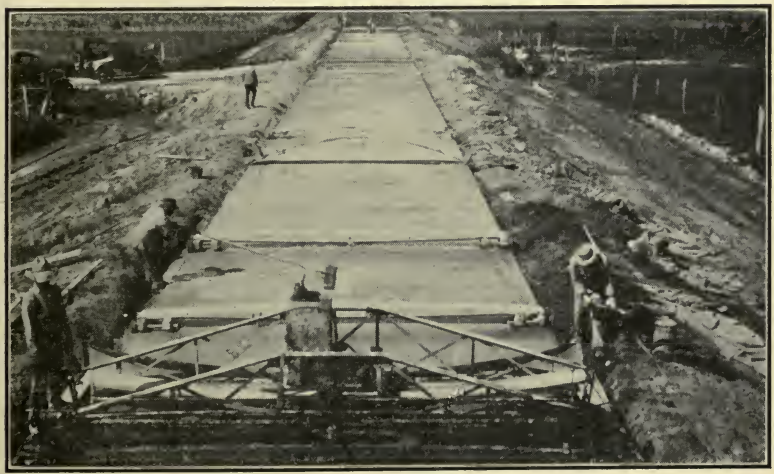


FIG. 72.—Complete finishing process. Tamping finisher in foreground. Equipment: tamping finisher, bridge, long-handled float, bridge, bow belt, burlap over pavement, covered-pavement, covering gang at work.

filling low spots if a perfect surface is to be secured. These matters are, however, of rather limited interest at the present moment as the tamping finisher are no longer manufactured.

TABLE X.—VERTICAL VARIATIONS IN SURFACE OF CONCRETE PAVEMENT FINISHED WITH TAMPING TYPE OF FINISHER[1]

	Distance from center of slab in feet																		
Longitudinal distance	1	2	3	4	5	6	7	8	9	10	9	8	7	6	5	4	3	2	1
Standard	36	28	21	16	11	7	4	2	1	0	1	2	4	7	11	16	21	28	36
Feet																			
0	29	25	20	13	9	6	3	1	0	0	1	2	5	8	12	17	24	28	34
1	38	29	23	16	11	7	4	2	1	1	2	4	7	10	14	18	24	30	36
2	37	32	24	17	12	8	4	2	1	2	2	4	7	9	14	18	25	30	35
3	39	32	24	16	12	8	5	3	2	2	3	5	8	10	15	18	26	30	34
4	40	31	24	16	12	8	6	4	3	3	4	6	8	12	16	20	25	31	35
5	38	31	23	16	12	9	6	5	4	3	3	6	8	14	14	20	26	32	35
6	36	31	24	17	13	8	6	5	4	5	5	7	10	15	17	21	27	33	36
7	36	32	24	17	13	9	6	5	4	2	4	6	9	13	15	19	25	31	36
8	37	32	25	19	13	9	6	5	3	3	4	5	8	14	14	18	24	32	34
9	37	32	26	19	13	10	6	4	3	3	4	3	8	10	13	18	24	31	33
10	35	31	24	19	13	11	6	4	3	3	3	4	8	10	14	18	25	32	34
11	34	32	24	21	13	11	7	4	4	2	2	5	8	11	15	19	25	32	33
12	33	29	25	21	15	11	7	4	3	1	2	4	8	10	14	19	25	32	36
13	34	30	26	22	16	12	7	4	3	1	3	4	9	12	14	18	26	31	33
14	35	30	26	23	16	12	7	5	4	2	2	4	8	10	15	20	25	32	33
15	34	31	28	23	17	12	7	4	3	3	4	5	9	11	15	20	27	32	36
16	34	30	26	21	15	11	6	4	3	3	4	5	8	11	15	20	26	31	34
17	34	31	27	20	15	10	6	4	3	4	4	6	9	12	16	20	27	31	36
18	34	32	25	18	16	9	6	4	3	2	3	4	7	10	15	19	25	31	32
19	33	30	24	16	13	8	6	4	2	1	2	4	8	11	14	20	25	31	36
20	33	28	23	17	11	8	6	4	2	1	3	5	8	10	14	19	25	31	33
Average	34.8	30.5	24.5	18.4	13.3	9.4	5.9	3.9	2.8	2.2	3.0	4.5	8.0	11.1	13.8	19.0	25.3	32.6	34.5

[1] All measurements in sixteenths of an inch from a plane 2¼ inches above tops of forms.

NOTE: As readings are in sixteenths of an inch, any variation of 5 or more in any vertical column, within 10 feet indicates a violation of the customary specification which limits variations to ¼ inch in 10 feet.

Irregularity in surface finish often is due to spading concrete under the plow. The tamping template will not smooth out material forced under the plow, and thus roughness is certain to result whenever spading of this sort is done. The tamp on machines of this type does not strike to a definite depth. It is carried on springs and thus rides over any pile of concrete too bulky to be driven down. This explains the fact that the surface which this machine leaves is governed by the work of the puddlers and that it often runs low by from ¼ to more than ½ inch.

Where machines of the tamping variety are in use, it is customary to use four men to puddle, one on the finishing machine, which commonly makes two or more trips over each area, and two or more men on re-treatment back of the finishing machine, the number depending somewhat on the methods in use and somewhat on the accuracy with which the work of the finishing machine is done. Figures 57 to 59 also give typical cross-sections from pavements where tamping finishers were used. Table X shows the longitudinal variation from correct gradient.

Hand Finishing.—Hand finishing is still permitted in many places and seems to be preferred in a few. This is, perhaps, not surprising, for at least in some of the regions where hand tamping and finishing are still in vogue, the concrete is often mixed too wet to be properly or satisfactorily handled by machine finishers. In some unfortunate cases, tamping finishers have been used on sloppy mixes with the results that soil from the base has been brought clear to the surface of the concrete. More often the fact that concrete containing a decided excess of water is in common use tends to delay the finishing. Such delays have sometimes been of considerable length. On a pavement once observed under construction, the water content of the concrete being outstandingly excessive, finishing had to be delayed from 2 to 3 hours. Of course a good deal of set had taken place by that time, and so the results obtained from the use of the finishing machine could not possibly have been satisfactory.

From the standpoint of the contractor, hand finishing is unavoidably expensive. If a smooth pavement is to be secured, the puddling must be done even more accurately than is required for the tamping finishers. The amount of labor on strike boards, screeds, etc., is considerably greater than is required on any finishing machine, and as these operations are as a general rule

less accurate than the better machine finishes, the amount of re-treatment, such as transverse floating, longitudinal floating, belting, rolling, etc. which must be resorted to in order to obtain a smooth surface is likely to be larger than is required where machine finishers are in use.

A still more important consideration, at least from the standpoint of the contractor, is that the capacity of a hand-finishing crew is limited. Finishing machines will handle more than 100 feet of pavement an hour without difficulty. A considerable number of extra men must be employed if a rate even approaching this is attempted on the basis of hand-finishing methods. The physical effort involved makes this unavoidable, particularly in hot weather. The most serious objection to hand methods, however, lies in the fact that where they are used, wet concrete is the rule. Every addition to the water content of concrete above that required to produce a slump of about 1 inch reduces its strength. Where hand finishing is in vogue, the crushing strength of concrete seldom averages (28-day test) much over from 2,500 to 3,000 pounds per square inch (6- by 12-inch cylinder basis). Where machine finishers are in use, the fact that drier concrete can be and in fact is used makes an average crushing strength (same basis used above) of over 4,000 pounds per square inch easily obtainable. Indeed, for individual projects, an average strength of 6,000 pounds per square inch has been secured. These figures are given merely to show how serious the sacrifice in strength really is, when wet concrete and hand-finishing methods are adhered to rather than change to the faster, more accurate, and more economical machine methods.

Re-treatment Processes.—Some of the processes which are used in the re-treatment of the surface after it has been worked over by a finishing machine are valueless. The roller, at one time much in vogue, and the various methods of extracting water from the concrete which have been devised to replace it constitutes an illustration. There is no excuse whatever for putting enough water into a mix so that any can be extracted later. Modern mixers will produce a workable mix with so little water that none will rise to the surface during finishing operations. Indeed, where the water content is held at a minimum, so little excess water is put into the mix that even the tops of the forms remain dry except as a stray bit of mortar is pushed out onto them. It is true that concrete as dry as this is not yet the rule

and that evidence is accumulating that it is not altogether desirable. Yet the fact remains that concrete as dry as this can be and indeed is being handled every day on many well-managed jobs. Moreover, the double-screed, the tamp-and-screed, and the tamping finishers do better work on concrete containing about 5 gallons of water per sack of cement (1:2:3½ mix basis) than they do on wetter mixes, because such mixes have enough "body" to hold the crown after it is formed. As these machines will keep up with the mixer easily enough when handling these dry mixes and will do this without using any extra men, there is from the contractor's standpoint nothing to be gained by the use of tools designed to extract water from the concrete in place. From the engineer's standpoint putting extra water into the concrete merely wastes strength. Finally, careful measurements show that the roller may somewhat distort the surface. There would, therefore appear to be no very sound basis on which to suggest its use.

The Longitudinal Float.—The longitudinal float is an effort to avoid the abrupt changes in longitudinal surface gradient which make a pavement unpleasant to ride over and cause impact. It seems to have done this with considerable success on hand-finished jobs, but it is valueless where a double sliding-screed finishing machine or a screed-and-tamp machine is properly used, for either of these machines is capable of turning out quite an accurate work as the longitudinal float will produce, as can be determined readily enough by measuring the finished work.

Object of Finishing Methods.—Finally, it ought to be remarked again that the primary objective in all finishing operations is a smooth pavement. None of the operations performed in finishing a pavement have any virtue in and of themselves, except as a certain amount of kneading or tamping is necessary in order to secure a proper degree of compaction throughout the body of the pavement. As this is adequately supplied, however, by any first-class finishing machine, the necessity for other finishing operations should be viewed solely in the light of their effect on the smoothness and the quality of the surface. Every operation takes time. Every operation costs something. Unless it can be shown, therefore, that an operation does, in fact, improve the smoothness or the quality of the surface by an amount sufficient to justify its cost, it ought to be eliminated.

Joints.—Some transverse joints are required in most pavements, and a good many are required under a few of the

prevailing designs. It appears likely that more joints rather than less will be required as the art of paving progresses. Most of the prevailing trouble with transverse cracks is due to the fact that the slabs laid are so long that the stresses in them are wholly indeterminate. The obvious means of correcting this trouble is so to reduce the slab length that the stresses in a slab are determinate, in short, to abandon empirical design in favor of rational design. This will, of necessity, mean more joints rather than fewer joints. Just how these joints will be formed needs no discussion here. The only important consideration from the con-

FIG. 73.—Finishing transverse joint.

tractor's standpoint is that a joint shall be required which he can place without delaying other operations. (See Fig. 73.)

The joints now used differ a good deal in design, and this, in turn, necessitates some difference in the practices used in finishing them. These differences are too numerous to cover in detail, but the principles involved in accurate economical work should be noted. In the first place, premolded joints on the whole appear to be the simplest to handle. These should be cut to the same thickness as the pavement. Two-, three-, and four-piece joints are cheaper than one-piece joints, but the laborers who set the joints cannot be made to understand that a gap between two pieces of joint material is unavoidably filled with concrete which, when hardened, forms a strut that may defeat the whole purpose

of the joint if it does not, indeed, cause more serious trouble. The joint material should be set about ½ inch low, the subgrade being cut out under it and backfilled against it, this to avoid the formation of bottom struts.

Joint Material.—The joint material must be held in an upright position, and for this purpose a steel plate is preferable to a plank, because its removal leaves less of a gap to be filled with concrete. A satisfactory practice is to stake the steel plate in place and, as soon as concrete has been placed on both sides of it, to remove it. Beside the fact that this avoids bottom struts, dropping the joint material ½ inch or more enables the finishing machine to handle its work just as though there were no joint in the pavement. It has never been possible to devise an entirely satisfactory method of finishing joints that are allowed to protrude above the surface of the pavement. In spite of the use of various types of split floats, occasional high joints are all but certain to develop. The submerged joint largely avoids this difficulty. It may be well to note, however, that the concrete over all submerged transverse expansion joints must be cut out and the edges tooled. In order to cut the joint to a line, a straight-edge should be laid across the green concrete and clamped to the forms to act as a guide for the cutting tool. This work must be carefully done, as any top struts will spall the surface near the joint.

The forms are almost never set to exact width. They tend to run a little wide, ½ to 1 inch being quite common. Premolded joint filler is cut quite exactly to proper length. It is, therefore, necessary to check the ends of each joint as the forms are removed in order to remove end struts.

Practices in Handling Joint.—In handling joints, the objective of the management must, of course, be a method which interferes as little as possible with other operations, is economical, but yields entirely satisfactory results. In other words, the ideal to be kept in mind in this, as in all other more or less minor items which must be handled in connection with paving jobs, is that the steady harmonious operation of the main organization, the business of which is to lay concrete, shall in no wise be hindered or interfered with by the minor operation. To accomplish this, what in principle amounts to a separate organization must be developed to handle the subsidiary operation, and methods of securing the desired results must be so worked out that they will

not in any way interfere with the major operation. The number of men used should in all such cases be large enough to make it certain that work on the minor operation cannot hold up the major operation.

As an illustration of this principle in the practices suggested above, the joint material is sunk below the surface so that ordinary finishing practices may proceed exactly as if there were no joints. The size of the crew which places the joint material, removes side struts, cuts top joints, molds the edges of these joints, etc. can be regulated according to the amount of work there is to do. The cost involved, when the work is handled in this way, cannot well exceed the time of two or three men. But

FIG. 74.—Laying the burlap.

if some treatment of the joint or some form of organization is adopted that delays finishing so that the yardage of pavement laid is reduced, the cost at once mounts rapidly. As a matter of fact, management is not always at fault when minor requirements obstruct production. Often the actual relation between minor requirements and the general production scheme is not as well understood by specification writers as it should be, with the result that arbitrary requirements governing methods are established, when what really is desired is merely a satisfactory result. This is unavoidable under present practices in specification writing, but if the job management is able correctly to interpret the desire back of such specifications and to show that satisfactory results can be obtained by methods more in keeping with the

general production plan, it usually will be found to be possible to secure a reasonable freedom of action.

Methods of Curing the Slab.—Specifications commonly require that freshly laid concrete pavement shall be covered with burlap or other suitable covering as soon as it has set enough so that the burlap will not mark the surface and that thereafter the burlap shall be kept moist for about 24 hours. It is then customary to remove the burlap or other material used as a temporary cover and to re-cover the surface with earth to a depth of about 2 inches. In some cases straw has been used instead of earth as a covering, and within the past few years there has been some use of calcium chloride, either as a surface application or as an admixture. Where calcium chloride is used, it is applied as soon as the burlap is removed. The ponding method, once very popular in the curing of concrete, has all but completely disappeared.

The Objective in Curing.—Whatever method of curing the slab is used, the objective is always the same, to insure the greatest strength which it is practical to obtain from the materials used. And just here is one of the greatest difficulties engineers confront in concrete paving work today, namely, that "the greatest strength it is practical to obtain" governs all considerations rather than some specific strength as a crushing strength of 4,000, 4,500 or possibly even 5,000 pounds per square inch. As long as this condition prevails, there always will be contention between those who think some specific strength enough, and those who are never satisfied, no matter what strength is obtained. The condition underlying this is the fact, previously alluded to, that pavement design today is empirical. Should it be shifted to a rational basis such as prevails in concrete structural design, to take a random illustration, this attitude would disappear. Engineers do not give much thought to the strength of the concrete used in structures, because the strength on which structural design rests is so low that it is attained except under the very worst conditions. In paving, the fact that the structure cracks badly under all ordinary conditions leads engineers continually to strive for a better grade of concrete in the vain hope that structural adequacy can thereby be more closely approached. A little study of the laws of flexure, of reversed stresses, for instance, in continuous trusses, where the stresses reverse over supports and may, under certain loadings, be very high, will serve to convince the thoughtful engineer that the search for structural adequacy

in improved strength is a delusion; that, in short, increasing the strength of the concrete can, at the best, only modify to a limited extent the slab length likely to result from cracking; and that if structural adequacy is to be attained, it will be necessary to get back onto the sound basis of well-established engineering principles. But until this is done, the demand for better and better concrete is likely to make economic deductions based on the assumption that concrete of any given quality is as good as conditions really require seem spurious.

Strength Required.—The author believes that concrete consistently showing a strength of 4,000 pounds per square inch in compression should meet any reasonable demand and is rather inclined personally to feel that a strength of 3,500 pounds would prove quite entirely satisfactory if the ordinary principles of design were used in paving work. This matter is mentioned here not only because it affects so much of the current thinking in regard to the particular matter under discussion—curing the concrete—but because it affects almost every angle of the engineer's contact with the concrete paving question. It would be a relatively simple matter to determine the cost of curing concrete by any of the methods mentioned above under any series of conditions. It would also be rather a simple matter actually to determine the effect of the various practices on the strength of the concrete, on its wearing qualities, etc., and on this basis definitely to determine what methods ought to be used. But because, when such determinations are made, no definite answer to the question of what method it is best to use can be given unless a specific quality in concrete is established and the effect on the attainment of this is developed, the whole problem remains unsettled.

The Contractor's View of Curing.—As a general rule, contractors prefer to use the chloride method in curing concrete. This arises first from the fact that the inadequate pipe lines in common use make the water supply a serious problem if a high rate of production is to be maintained. Another reason is that once the chloride is on the pavement, it ceases to be a source of contention with the inspectors. Very soon after it is spread, it liquefies and thereafter there is no basis on which to rest an argument that it was not carefully applied. Another important consideration is that, where it is used, pumping equipment can be released more quickly in the event a move must be made. Where water is used for curing, the water supply must be kept up for a week

or longer after laying pavement has been completed. If a move involves a new plant set-up and a new pipe line, water curing either causes delay or requires the use of additional pipe and extra pumps.

Direct Cost of Chloride Curing.—The direct cost of chloride curing is, on the whole, a small part of the problem from the contractor's point of view, and his preference for chloride curing is based on other considerations. As a general rule, the direct cost of the chloride and its application is higher than the direct cost of earth covering. The former, as generally practiced, takes the time of two men in addition to from 2 to 3 pounds of chloride per square yard of pavement. Applying the earth covering takes the time of a varying number of men depending somewhat on the rate at which the pavement is laid and somewhat on the character of the material in the shoulders, but ordinarily from six to eight laborers are used on this work. Sprinkling keeps one or two boys at work. Removing the covering is not much of an expense, as it is done with a blade, the material used in covering being thrown onto the shoulders there to await the final dressing up of the work.

The Effect of Chloride Surface Treatment.—As the effect of calcium chloride on the concrete is still a moot question, this will not be discussed here further than to remark that where it is used as a surface dressing, it is a common thing to find that the surface has a dead appearance, that scaling results, and that where bits of a surface which has been treated with calcium chloride are examined carefully, there is every appearance of a chemical action that has been destructive of much of the normal strength of the concrete. Probably this does not penetrate far into the slab and so the effect may not be of much consequence. It does, however, somewhat mar the appearance of the surface.

Adequate Pipe and Pumps Needed.—The objection so often raised to water curing would be largely eliminated if contractors would install adequate water delivery equipment, pipe of proper size, enough of it, and pumps of proper size. This matter has been discussed in the chapter on water supply, but it seems pertinent to remark here that it is quite as essential that the water supply equipment be adequate as that any other part of the equipment be adequate. Small pumps and small pipe lines, always overloaded when water must be pumped any distance, are the cause of most of the indirect losses now encountered in water curing the concrete. If these were corrected, there would be less reason to

feel that chloride curing has advantages because of the favorable effect on indirect losses which a reduced water supply has.

Shouldering and Clean Up.—Shouldering and the final clean-ups are sometimes separate items though often they are covered in the price bid on the slab. Methods and practices governing these methods are so variable that it has been deemed advisable to omit any discussion of them. In any event they generally are more closely related to the grading operations than to paving.

CHAPTER XV

THE ORIGIN AND COST OF OVERRUNS IN MATERIAL

Overrun is the use of more material than is theoretically required to produce a given quantity of concrete. Overrun is a common source of expense in concrete pavement construction. As it is incidental to construction operations, it falls to the superintendent to guard against it as far as this is possible. Some of the causes will, at times, be beyond his control, as they rest on specification requirements, but most of the causes can be reached and so can be eliminated.

Overrun Not Always Known.—As a general thing an overrun in cement is obvious because the cement used is so carefully checked. But overruns in sand and in coarse aggregate attend overruns in cement. Because no day-to-day check is kept of these materials, however, overruns here are more apt to escape notice. Overruns in such minor materials as reinforcing steel, parting strip, joint material, etc., also occur, but they are of minor importance.

The Causes of Overrun.—The more important causes of overrun are as follows:

1. Short shipment and loss in weight.
2. Storage losses.
3. Spillage incident to hauling and spillage over the forms.
4. Careless form setting.
5. Low subgrade which includes all careless work on the subgrade.
6. Bulking of the sand.
7. The use of sand that is too coarse.
8. The use of coarse aggregate having too high a void content.

Materials Should Be Checked as Received.—It is important to see that any material purchased is actually received. All materials should, therefore, be checked as nearly as possible by measurement or by count as they arrive, and claims should be made promptly for any shortage. It is not a common thing to find that there is any serious shortage either in the aggregate or in the cement. Inaccuracies of one sort or another, however,

are bound to occur no matter how carefully shippers try to avoid them, so, as a general rule, the expense of maintaining a check on materials is fully warranted.

The Effect of Moisture on Weight.—Where aggregate is purchased by the ton, a more important loss may result from the fact that aggregates, particularly sand and gravel, are quite generally loaded wet. Most of the water runs off, but a good deal is retained; thus the weights paid for are almost certain to exceed the actual weight of material secured, unless there is a definite deduction for moisture content. This fact will be developed at once if a weighing batcher is used and any check is kept on receipts at the yard and tonnage sent to the mixer, but it often escapes notice when the batches are measured. The sand generally carries a higher moisture content than the gravel, but this is by no means always true, and in either case the moisture content in freshly washed aggregate is enough to cause an apparent overrun if these aggregates are paid for at scale weight.

Storage Losses.—Storage losses are inevitable wherever any stock piling is done. These losses have been discussed more at length in connection with material delivery (see pp. 139 and 141) and so will only be noted here as one of the common sources of overrun in the sand and in the coarse aggregate. Field stock piling must be rather carefully handled if losses are to be reduced much below 10 per cent of the material stock piled. Where all the materials are taken from the yard direct to the mixer in trucks or by industrial railway, a considerable proportion of the material going from the cars into the hoppers, losses, under careful management, need not exceed 2 per cent of the material handled.

Handling Losses in Cement.—There is likely to be some loss of cement due to broken sacks, etc. With care, however, this loss need not amount to much, and if a good sack cleaner is in use, the recovery of cement here should offset storage losses, broken sacks, etc.

Other Losses Affecting Production.—Losses due to short shipment, to weighing aggregate when wet, and to wastage in the bottoms of stock piles have little or no effect on the conduct of the job as a whole. The cost of these losses is, therefore, equal merely to the cost of the material lost at the point where the loss took place. At that, the losses sustained in these ways may run into a good many hundreds of dollars during a season's work. In considering the rest of the items in the list of causes of

overruns, it is, however, necessary to keep in mind the fact that these not only cause the loss of material but also cut down production. In determining the cost of anything that hinders production, it naturally is necessary to determine the amount production is hindered, and to do this with any degree of accuracy it is necessary to proceed on the assumption that laying a concrete pavement is a series of coordinated operations so dependent on each other that to stop one stops the whole job. Thus the subgrade is prepared as needed, the forms are set as needed, and the pavement is finished as the concrete is mixed. All of these operations are tied together. The contractor does not finish 500 feet of subgrade a day; he keeps subgrading about 500 feet ahead of the mixer. He does not lay 500 feet of forms a day; he keeps the forms about 500 feet ahead of the mixer. Such operations move fast or slow as the production of the mixer dictates. The contractor has, in short, an organization which, so far as it is engaged in producing concrete pavement, should be considered as a whole. But overruns in material other than those already noted result chiefly from the fact that a given measured amount of material, that is, the individual batch, fails to produce the correct amount of pavement. But as the amount of work which can be done in a day is governed by the number of batches that can be handled, it naturally follows that if the batch produces less than the proper amount of concrete, the day's run is correspondingly reduced. The fact that the cost of operating a paving organization is about $400 a day has been fully developed in other parts of this book. If, now, production is at the rate of 1,000 feet a day, the cost of labor, equipment operation, equipment depreciation, overhead, etc. per foot of pavement laid is about 40 cents, but if only 500 feet is laid, the cost is about 80 cents. It naturally follows, then, that whatever lowers the production per batch increases the cost of labor, etc. by an amount per foot of pavement lost which is in harmony with the cost at which pavement is being laid and of a value per foot of pavement which is of the general order just given.

Spillage and Related Losses.—Returning now to the causes of overrun, it will be apparent that spillage over the forms is a loss of materials that causes a direct and a proportionate loss in production. If the batches used should have produced 500 feet of pavement but, because of spillage over the forms, too great a distance between the forms, form spreading, or other causes of

this nature, actually produced only 490 feet, labor and equipment depreciation values worth about $8 literally have been thrown away, and if this is continued through a working season of 150 days, the total loss amounts to over $1,200.

Low subgrade and careless work on the subgrade (see Figs. 59 and 65) also cause losses which can be readily corrected. The proper methods to use in preparing the subgrade have been discussed in Chap. XI. But where careless work is done in subgrading and in fine finishing, a loss of as much as 5 per cent from this cause, though not common, is occasionally seen. If, then, because of poor subgrade, batches which otherwise would have laid 500 feet of pavement are producing only 475 feet, there is a loss of labor, equipment depreciation, and related values, which at 80 cents per foot ($400 ÷ 500) amounts to perhaps $20 a day, or about $3,000 during a good working season. To this and to the spillage losses discussed above must, of course, be added the cost (delivered at the mixer) of the materials involved. These are easily calculated, as they are direct losses and in percentage agree with the loss in footage.

The Effect of the Bulking of Sand.—Bulking of the sand may cause an indirect loss. Let us assume that a 1:2:4 mix is being used. If the sand does not bulk and the coarse aggregate has, say, 40 per cent of voids, the result will be somewhat as follows:

	Cubic Feet
Mortar	2.2
Voids in coarse aggregate 4 × 0.4	1.6
Excess mortar	0.6
Coarse aggregate	4.0
Production per bag of cement	4.6

Now if by reason of the bulking of the sand (taking rather an extreme case) the actual volume of sand is reduced to 1.4 cubic feet, the amount of mortar will be reduced to about 1.6 cubic feet, with the result that at least substantially the following condition will obtain:

	Cubic Feet
Mortar	1.6
Voids in coarse aggregate 4 × 0.4	1.6
Excess of mortar	0.0
Coarse aggregate	4.0
Production per bag of cement	4.0

Loss in production (4.6 − 4.0) = 0.6 cubic feet per bag or about 13 per cent

In this case the batches that should have produced 500 feet of pavement will produce perhaps 435 feet, the loss being a little over 65 feet per day, the labor, equipment depreciation, equipment operation, and overhead costs on which have been shown to be worth about 80 cents a foot, or over $50 a day, which is more than $7,500 during a full working season!

The loss on materials is not quite so easy to calculate, though no real difficulty exists here. When a batch containing the right amount of cement and the right amount of stone is used, only 4.0 cubic feet of concrete result where 4.6 cubic feet should result. On this account the number of extra batches required in order to produce a given footage, that is, the overrun in batches, will amount in this case to 15 per cent. From the resulting extra cost of coarse aggregate and cement, the saving on sand must be deducted. Only 70 per cent of the correct amount of sand is being used per batch, but as there are 115 per cent of the correct number of batches, the sand actually used (70 × 115) is slightly over 80 per cent of the amount estimated.

The Use of Coarse Sand.—The use of sand which is too coarse may sometimes produce an effect similar to the bulking of sand, though it is more apt to produce a yield higher than normal. To act as mortar, sand must be so fine that it will fill the voids in the coarse aggregate without expanding them. Much concrete sand is too coarse for this, so much so, in fact, that the coarser particles act as part of the coarse aggregate rather than as part of what is, in ordinary conceptions of this matter, deemed to be the mortar. In fact, when ordinary well-graded gravel is used, most of the material retained on a 10-mesh sieve acts in this fashion. Take, then, a sand 20 per cent of which is retained on a 10-mesh sieve, and assume that it is to be used with an ordinarily well-graded gravel having a void content in the

neighborhood of 40 per cent. If, in a 1:2:4 mix, the sand all functioned as mortar, the result would be something like this

	Cubic Feet
Mortar	2.2
Voids in gravel 4 × 0.4	1.6
Excess mortar	0.6
Gravel	4.0
Production per sack of cement	4.6

Actually something like this will result from the use of a sand as coarse as this, assumed proportions being 1:2:4 and actual proportions, about 1:1.6:4:4.

	Cubic Feet
Mortar, about	1.8
Voids in coarse aggregate 4.4 × 0.4	1.76
Excess mortar	0.04
Coarse aggregate	4.4
Production per bag of cement	4.44

In this case the shrinkage due to the use of aggregate that is too coarse is 4.6 − 4.44, or 0.16 cubic foot, about 3.5 per cent. Labor and equipment losses would be calculated as in the cases cited above. As the correct amount of material in each batch has simply produced a denser mix, the increase in materials is direct, applying to each one alike, and is about 3.5 per cent.

Coarse Aggregate Containing a High Void Content.—The last case is that of coarse aggregate having a large void content. Here the general effect is similar to that shown in the last two cases. Assume a 1:2:4 mix and the comparative effect of using coarse aggregate having a void content of 50 and 35 per cent. Results will be about as follows;

	Cubic Feet
In the first case:	
Mortar	2.2
Voids in coarse aggregate 4 × 0.5	2.0
Excess mortar	0.2
Stone	4.0
Production per bag of cement	4.2
the second case:	
Mortar	2.2
Voids in coarse aggregate 4 × 0.35	1.4
Excess mortar	0.8
Stone	4.0
Production per bag of cement	4.8

In this case the difference in the amount of concrete produced per batch is 4.8 − 4.2, or 0.6 cubic feet, or 12.5 per cent, about the same as that shown for the illustrative example under the bulking of sand; and the extra cost of labor and equipment, etc. would be about $7,500 a year. The materials would all overrun about 15 per cent, the number of batches required if stone of high void content is used being about 115 per cent of what would be required if stone of low void content were used (see also discussion of this matter in Chap. III).

The Effect of a Short Batch on Production.—In the illustrations used above, a normal production in the neighborhood of 500 feet per day has been used in showing how cost is affected. This has been done for the reason that it is a fairly common average rate of production. The case can, however, be carried further. The batch is the actual unit of production on concrete paving jobs. In the last analysis it costs just as much to handle a batch which is 90 per cent of full size as it does to handle a full batch. It also is a fact of general application that it costs a contractor no more to obtain practically full production—45 or 46 batches an hour, under a 1-minute mix—than it costs him to produce 24 batches an hour, or 14 batches an hour, for he must in either case have the same equipment and approximately the same force. Whatever causes his batches to run short, and that is what each of the losses which have been discussed does, decreases the output per day, which causes an equivalent increase in cost per lineal foot

or per square yard of pavement laid. This, of course, causes an equivalent increase in the total working period required to complete the job. In short, if each batch runs 10 per cent short, there is no escape from the fact that the contractor will have to work enough extra days to make up for this loss. His batcher plant, his subgrading, his trucks, his whole plant must run while he is making up whatever time is lost due to short batches, batches that it would have been just as easy and just as cheap to handle if they had been full batches; so he must charge for all of this extra time in counting the cost of underrun.

Another Angle on the Effect of the Short Batch.—There is another way of putting this which may throw some light on it. If the batch is short, footage underruns. If it underruns 10 per cent, a little over 11 days' work is required to lay the same footage which, with a full batch, would have been laid in 10 days. This is true no matter what the rate of production is, whether it is 500, 700, or 1,000 feet a day. The proper method, then, for a contractor to adopt in determining what overrun costs him is first to determine his daily labor, equipment depreciation, overhead, and other costs. Each per cent of overrun works to reduce the production secured through this expenditure by about 1 per cent. If the contractor lacks definite knowledge as to what the daily cost of operation is on any specific project, it is a safe general rule to assume that, as on most jobs these expenses amount to about $400 a day, expenses other than the cost of the materials lost as a result of overruns are increased $4 a day by each per cent of overrun and that for a normal full working season this will amount to $500 for each per cent of overrun. The seasonal cost of overrun, the cost of material excluded, is, then, about as follows:

1 per cent overrun	$ 500
5 per cent overrun	2,500
10 per cent overrun	5,000
15 per cent overrun	7,500

These are, of course, generalizations but are close enough to the facts for most uses to which they are at all likely to be put.

Method of Determining Cost of Overruns.—It is also a reasonable approximation to the facts to assume that the per cent of the overrun in other materials is equal to the per cent of the overrun in cement. This is not quite always true, for, as was shown above, overrun due to bulking of the sand is partially offset by

underrun in the sand. It is also true that underweight, stockpile losses, etc. in general affect only the aggregate. As all of the other common causes of overrun affect the materials equally, however, the overrun in cement may be safely used as a general basis from which to determine the amount and the cost of overrun. As a general rule, not specifically accurate in detail but sufficiently accurate for most purposes, the cost of overrun then may be determined as follows:

1. Compare cement used with quantity theoretically required.
   Example:

Used	146,728 sacks
Theoretically required	132,300 sacks
Overrun	14,428 sacks
	or 10.9 per cent, say 11 per cent
Mix 1:2:4	
Working time	90 days

2. Multiply overrun in sacks of cement by sand content in mix to obtain overrun in sand and by coarse aggregate content in mix to obtain overrun in coarse aggregate.
   Example:
   Sand overrun (14,428 × 2), 28,856 cubic feet, or 1,068 cubic yards
   Coarse aggregate overrun (14,428 × 4), 57,712 cubic feet, or 2,136 cubic yards
3. Extend cost of labor equipment, etc. at $4 per day per per cent of overrun for the period during which the overrun has prevailed.
   Example:
   $4 × 11 (per cent overrun) × 90 (days worked).. $3,960.00
4. Extend material costs.
   Example:

14,428 sacks cement at 60 cents	$ 8,654.80
1,068 cubic yards of sand at $1.50	1,602.00
2,136 cubic yards of gravel at $2.00	4,272.00
Total cost of overrun	$18,488.80

This could be readily extended to give the cost of the overrun per square yard of pavement laid or in any other unit desired, but ordinarily this would not be of much value, as what the contractor wishes to know is the gross cost involved. Moreover, the exact cost of overrun commonly is of no more value to him than is a reliable approximation. The above methods of calculation are therefore presented in the hope that they will assist in developing an appreciation of the really serious nature of overruns and therefore of the responsibility which rests on the superintendent to do everything necessary in order to eliminate them.

CHAPTER XVI

ORGANIZATION AND EQUIPMENT

Before there can be any certainty that terms used will mean to the reader what they mean to the writer, or that any conclusion as to equipment and personnel requirements, though they are based on extended field observations, will seem to the reader to be justified, it is necessary to define a little more closely some of the terms used. The operations discussed in this chapter, therefore, are more definitely described as follows:

Preparing Subgrade.—This covers all operations incident to converting a rough subgrade, which has previously been brought to the proper grade, to such shape and condition as is required for the placement of the pavement. Preparing subgrade, however, as here used, does not cover any work required in bringing the rough subgrade to the proper grade. This must be considered as part of the grading work and, as such, is a separate item.

Handling Forms.—This covers all work incident to taking up used forms, cleaning them, moving, setting, aligning, oiling, and otherwise working with the forms.

Handling Materials.—This covers all work incident to unloading cars, storing or caring for materials, loading job transportation units, and unloading them into the mixer skip. It also covers the water supply.

Hauling Materials.—All work of transporting materials and all work done on or in connection with the use and care of transportation equipment is included under this designation.

Mixing.—This includes the operation of the mixer and all work on the mixer.

Finishing.—All work of placing materials (puddling), finishing, covering, curing, etc. is included under this designation.

Miscellaneous Operations.—Miscellaneous operations, such as the placing of joints, parting strips, and reinforcing steel, are non-standard operations; that is, while they may be a part of the general operation of laying concrete pavement, they are not a necessary part of it. In some places all of these operations, and

perhaps others not specifically referred to here, are required. In other places part of them will be required. In others none will be called for. The effect of these and other miscellaneous items on the amount of labor required will be discussed briefly, but because there is not the uniformity in practice in these items that there is in regard to the operations listed above, it appears to be advisable in discussing them to separate them from the more standard operations.

Scope of Discussion.—It has been noted that the personnel and the equipment for a job depend on the methods in use and the efficiency with which these are carried out, as well as on the specific operations performed. It is, therefore, desirable at least to outline the methods on which a statment of personnel and equipment rests, just as it has been shown to be necessary to outline the operations covered. The preceding chapters have made extended reference to methods, but such additional reference to them as seems necessary in order to clarify the relationship between methods on the one hand and personnel and equipment on the other is made in presenting the schedules of personnel and equipment, in order more definitely to connect the two. The methods on which these schedules are based have been selected from among those observed in practice, and most of them have been subjected to trial in connection with the efforts made, on a number of jobs, to increase production. They are the simplest and the most direct methods that have been found, and while it is recognized that occasions may arise in which they will not prove altogether appropriate, they at present appear to be the best that have been developed for this work. No job has ever been observed on which all of these methods were in use, but it would appear that there is no basic reason to suppose that in combination they would be less efficient than they have been where observed in use in combination with practices not recommended.

Preparing the Subgrade.—The rough grade having been brought to proper grade (this being in fact a grading operation, see Chap. IV), the first operation incident to laying a pavement is to cut out for the thickened edge, at the same time cutting wide enough to take out most of the material that must be moved to make room for setting the forms. The proper tool for this work is a fairly heavy blade; while this can be drawn by horses, it is better to use a 5-ton crawler type of tractor, as the operating

space required is less, and the usefulness of the tractor in general service about the job is greater. The forms should then be set, after which the width of the subgrade on which the pavement is to rest should be thoroughly broken up by a scarifier, and a crown formed by the blade and 5-ton crawler-type tractor and trimmed to correct section by a first-class subgrader, surplus material being removed by hand or by a fresno, depending on the accuracy with which the rough grade was finished. In performing this operation, the subgrade should be left from ¼ to ½ inch high and then lightly rolled by a light (1½-to 3-ton) roller, after which, to insure accuracy of cross-section, the forms should be checked and the subgrader used again with the blades adjusted to cut to exact cross-section. Behind the mixer, a heavy fine finisher (often known as subgrade planer) should be attached to the mixer to be dragged along by the mixer as it moves ahead.

These operations in preparing the subgrade require the following equipment:

1 blade grader, heavy duty, 8-foot blade
1 caterpillar tractor, 5-ton size
1 scarifier
1 subgrader
1 fine finisher
1 light roller

The labor requirement is as follows:

1 tractor operator, who can act as subforeman
1 blade operator
2 laborers with the tractor
1 roller operator
1 laborer at the mixer to take care of the fine finisher and perform miscellaneous tasks

Form Setting.—Until very recently form setting has been a manual operation in all of its phases. No heavy equipment is required for it except, as noted above, that the blade grader should take out most of the material which has to be removed before the forms are set. Recently a form grader designed to cut a bed for the forms has been so far perfected that it is appearing on a good many jobs. This machine is well built and can be made to do the work of preparing the bed for the forms as accurately as it can be done by any but the most experienced hand operators. It should be observed, however, that the device so far developed for guiding the operator in determining whether he is

cutting exactly to grade falls far short of perfection with the result that, while the machine as a whole gives excellent promise, many operators find it difficult to work as close to exact grade as is desirable for accurate and easy form setting.

If the soil is reasonably easy to work, and the practice of cutting the bed just below grade and setting forms on a thin layer of loose material is followed, three men—one to cut the trench and two to set the forms—can be trained to handle all the form setting, though more commonly one or two more than this are used. Beside this, two laborers are required to take up used forms and load them on the wagon in which they are hauled back and distributed to the form setters. A team and wagon are better and cheaper for moving forms than a truck. It can get over the shoulders and through the ditches better, the greater speed of which the truck is capable on good roads being of little advantage in this work because of the time consumed in loading and unloading as well as because of the bad going. The work of moving the forms commonly takes less than the full time of this force, and it is, therefore, available for such other duties as cleaning and oiling the forms, for setting forms when this is necessary, or for any other miscellaneous duties that may be required.

In addition to the laborers who are working on forms, a foreman is needed to keep things moving smoothly. As the form setting and the subgrading are closely related, it is well to put a good foreman over the two operations, allowing him to use the tractor operator as a subforeman in charge of subgrading operations when his duties require him to be at some other point on the job.

The Work of the Foreman.—In this connection a word may be said as to foremen. Some contractors want what they term working foremen, that is, foremen who work with the men, doing much the same tasks and assisting generally in the ordinary work of the day. This is a poor practice. Keeping a dozen men effectively at work is task enough to demand the whole attention of any ordinary foreman, and if high efficiency is to be attained in pavement construction, it will generally be helpful to make this perfectly clear. Indeed all foremen should understand that they are employed to keep the men under their direction at work and the work for which they are responsible moving smoothly and that, no matter how hard they may work themselves, unless

they actually accomplish this, their value is lost. The practices here noted require the following equipment:

5,000 lineal ft. forms
1 wagon
1 team, 2 horse

The labor requirement is as follows:

1 foreman
1 laborer to cut trench for forms
2 laborers to set forms
2 laborers to remove forms
1 teamster

Handling Materials.—The most satisfactory material plant is an oil or gasoline crane of the crawler type with a ¾-yard bucket (a 1-yard bucket may be desirable if a high rate of production on the basis of a six-bag batch is to be had) and a steel bin equipped with a modern fast-dumping, batch-weighing device. One operator is needed on the crane, a laborer in the cars, and a hopper operator. At the cement house, a belt conveyor should be used for elevating the sacks to a point where they can be emptied into hoppers from which the cement can be discharged into the delivery equipment. Three men are needed in handling cement in this way. A sack cleaner and a sack baler should also be installed here, their operation requiring the time of one man. At the mixer the trucks must be turned around before they can be backed to the mixer and dumped. This should be done on a turntable. One man is required to operate the turntable, and from time to time the tractor must be sent back to move it down the subgrade out of the way of the mixer.

At the mixer, one man is needed to help in dumping the trucks. The endgate must be released to allow the truck to discharge its load, and after the load is discharged, the gate must be closed and locked. Often a little material not deposited in the skip must be salvaged.

For handling the water a pump is required. One man commonly is used to look after it. The supply of pipe will depend entirely on local conditions, but as a general practice at least 20,000 feet of 3-inch pipe with fittings and a take-out connection for every 300 feet of line should be available. If take-out connections are provided every 300 feet, the equipment for water

delivery will include two lengths of 2-inch pressure hose about 200 feet long to feed the mixer. To prevent loss of time in changing hose, the mixer should be provided with a double hose connection so that the second hose can be connected before the first is disconnected.

The pipe is commonly laid before mixing starts and during the move from one mixer set-up to the next. When laid in this way, labor and transportation equipment which otherwise might be idle or assigned to more or less non-productive work is used in moving the pipe. Though pipe must be maintained in position for some days after the concrete is placed in order to furnish water for curing, it generally is possible to synchronize removal and relaying operations with the mixing operation, at least to such an extent that the amount of work to be done on the pipe line when a move is made is materially reduced. In the interest of prompt moving the relaying should be entirely completed before the move is begun. To make this possible, the quantity of pipe and fittings which will be required should be carefully determined before the job is begun and sent to the job with the other equipment. If this is done, removal and relaying can be so handled that the pipe line will never delay a move. When handled in this way, the time of three men is all that is required in handling the pipe line. Generally no extra transportation is needed, as the team used for hauling forms can ordinarily find time to move the pipe. If the team handling forms cannot do this work, it is customary to use a spare truck on this work. Finally, to keep the supply of all materials running smoothly, it is well to place this work under the direction of a good foreman. It is one of the outstandingly important elements of the job and should be carefully supervised.

Handling materials, including water delivery, under these practices will require the following equipment:

1 crane, crawler type, ¾- or 1-yard bucket
1 steel hopper, with modern batch-measuring or batch-weighing device
1 cement house, with cement loading bins
1 belt conveyer for cement house
1 sack cleaner
1 sack baler
1 pump, 100-gallon capacity at 400-pound pressure
20,000 feet of 3-inch common steel pipe with fittings
400 feet of 2-inch pressure hose (in two sections)
1 turntable

The labor requirement is as follows:

1 plant foreman
1 craneman
1 hopper operator
1 extra man to help unload cars
3 cement handlers
1 laborer to clean and bale sacks
1 pump operator
3 laborers to handle and lay pipe
1 turntable operator
1 truck dumpman

Material Delivery.—The equipment required for material delivery is the most variable element on a paving job; it must therefore be determined for each project. Beside the transportation equipment, each job should have a reasonably well-equipped repair shop with a skilled mechanic in charge to keep the equipment in good running order. Naturally, as such a man may be expected to spend most of his time working on the trucks, he should be particularly well trained in caring for these, but he should know something of other types of equipment as well. On most jobs the mechanic should have a helper who may well know something of blacksmithing. (For a full discussion of truck delivery, see Chap. VII.)

The Use of Bonuses.—There are a few key positions on any sort of work where it is outstandingly expensive to hire cheap men. The job mechanic holds one of these positions, the craneman another, and the mixer operator another. In any of these positions the best man that can be obtained is not too good. As high production always means extra-hard work for these men, a wage scale based at least in part on the production obtained is always worthy of consideration. A scale based wholly on production would, from the contractor's standpoint, be perhaps even more desirable, but the objection to this lies in the fact that superintendence quite generally is the weakest element in the contractor's organization, and these men are not in a position to develop high production if the superintendence is weak. They can respond wholeheartedly only when good superintendence makes high production possible. In view of the common occurrence of poor superintendence, it is unfair to ask such men to work wholly on a production basis, for the risk they assume in accepting such an arrangement is too great. A far better and

fairer way is to pay the standard wage and offer a bonus for production over some specified output.

Equipment and Labor Required in Mixing.—The equipment requirement for mixing is one mixer and the labor requirement is one operator.

Finishing Equipment and Personnel.—The first operation in connection with finishing is the spreading of the concrete, commonly called puddling. Two puddlers will be able to do all the spreading necessary and do the spading along the forms as well, if the mixer operator is properly skilled and a double-screed finisher is used. No heavy equipment is needed in connection with this operation.

Shaping the crown and working and compacting the mass should be done by a double-screed finisher. When operated over concrete of proper and uniform consistency, the surface produced by this machine is conspicuously uniform. Following immediately behind this machine, if hand work on the surface is required by the specifications, one man with a long-handled float can wipe out the screed marks and check the surface with a 10-foot straightedge. The final belting follows the checking of the surface with the straight-edge, and, for this operation, the finishing machine operator ordinarily can be called on to aid the finisher, as his time is seldom taken up fully in running the finishing machine.

Where specifications will permit, the finishing machine can be made to do its own belting. If this is done, the long-handled float may be dispensed with but in order to do this satisfactorily, three trips should be made by the finishing machine instead of the two now accepted as standard.

Covering the pavement with burlap or other temporary cover commonly requires two men; the earth covering commonly requires some six men more; and watering, if well done, two more. The equipment required for finishing is then:

1 finishing machine, double sliding screed

The labor requirement is:

2 puddlers
1 finishing machine operator
1 finisher (where specifications require)
2 laborers to spread canvas
6 laborers to cover concrete with earth
2 laborers to sprinkle the concrete

In addition to the labor requirements above discussed, common practice and good judgment dictate the employment of a superintendent, a timekeeper, a watchman, and a water boy.

Miscellaneous Labor and Equipment Requirements.—A center joint is now quite commonly required. Where it is used, a line of ¾-inch steel is often placed along each edge. Sometimes other steel is also used. Placing the center joint and the two lines of steel requires the time of two men. If additional steel is used, an extra man may be required. These men also assist on odd jobs about the mixer.

If the edges are rounded and center joint is formed over the parting strip and if the transverse joints are worked out, from one to four masons will be required, the number depending on the amount of this work there is to do and the care required in doing it.

TABLE XI.—PERSONNEL REQUIRED WITH MOST EFFICIENT EQUIPMENT

Rough grading:	
Grade foreman	1
Plowholder	1
Teamsters	2
Fine grading:	
Tractor operator	1
Blade operator	1
Roller operator	1
Subgrader operator	1
Laborers	2
Handling forms:	
Foreman	1
Teamster	1
Laborer, to set forms	3
Laborer, to strip forms	2
Handling materials:	
Plant foreman	1
Crane operator	1
Hopper operator	1
Cement handlers	3
Bag baler	1
Pump operator	1
Laborer on pipe line	3
Turntable operator	1
Truck dumper	1
Laborer	1
Hauling materials:	
Mechanic	1
Helper	1
Drivers, delivering material	As required by the haul
Mixing:	
Mixer operator	1
Finishing:	
Puddler	2
Finishing machine operator	1
Laborers to finish concrete	1
Laborers to spread canvas	2
Laborers to cover concrete	6
Laborers to sprinkle concrete	2
Miscellaneous:	
Superintendent	1
Timekeeper	1
Watchman	1
Water boy	1
Total (without drivers or miscellaneous)	46

TABLE XII.—MOST EFFICIENT EQUIPMENT

Rough grading:	
Plow	1
Fresno	2
Fine grading:	
Blade grader	1
Caterpillar tractor—5 ton	1
Scarifier	1
Subgrader	1
Fine finisher	1
Roller	1
Handling forms:	
Forms, lineal feet	5,000
Wagon and team	1
Handling materials:	
Crane	1
Hoppers	1
Conveyer (cement)	1
Cement house	1
Pump	1
Pipe (lineal feet) 3-inch	20,000
Hose (lineal feet) 2-inch	400
Turntable	1
Sack cleaner	1
Sack baler	1
Hauling materials:	
Trucks	20
Service truck	1
Mixing:	
Mixer	1
Finishing:	
Finishing machine	1
Miscellaneous:	
Repair shop	1

Placing Joints.—The methods used in placing joints differ widely. Where the joint material must be placed on a special plate and this placed and then removed, two men are assigned on this work and, when not so engaged, help on other work. If the joints are put in against a wooden plank or a plain steel plate, the crew handling parting strip and steel may be increased by one man and the work of setting joints done by this group. In general from one to four extra men are required where transverse joints are used, the number depending on the spacing of the joints and the method used in placing them.

Minimum Labor Requirements.—One other matter may be referred to again at this point. Reference has been made a number of times to the fact that in many of the operations incident to laying a concrete pavement the labor requirement is fixed; that is, it cannot be reduced even though the rate of production is low. A brief scrutiny of the personnel and equipment as given above will show the reason for this. Thus, at the material plant, a craneman, a helper to assist in unloading cars, a hopper operator, and three men handling cement appears to be an absolute minimum. The equipment cannot consistently be operated with less than this force even if production falls to 100 feet a day. On the other hand, some members of this force are not working to capacity even when the six-bag paver is running at 48 batches an hour. Much the same thing is true of most of

the other operations. The subgrade crew, for instance, requires a tractor operator, a roller operator, and at least two men, no matter how low production falls, because the equipment cannot be operated with less. The mixer cannot be operated by less than one man, and the finishing can hardly be reduced below the one man required to run the finishing machine. There is no need to continue the recital of these minimum requirements to confirm the statement made in other chapters that cutting down the number of batches per hour raises the cost of paving, because neither the investment in equipment nor the amount of labor employed can be correspondingly reduced. Rather the path toward lower cost lies along the line either of increasing the size of the mixer or of reducing the time of mixing. By either process a closer approach can be made to the full utilization of the capacity of the men and equipment required in the secondary operations.

Possibilities of Higher Production.—"The men don't seem to be working a bit harder," remarked a contractor when production on his job had been raised from an average of about 63 feet an hour to an average rate of nearly 100 feet an hour. That was visibly true. The difference was simply in the fact that they were wasting less time. How much further this would have been true remains to be seen. It is, however, apparent that a high-grade mixer running at the rate of about 15 revolutions a minute can turn out first-class concrete in a minute. Experiments now under way to determine whether the mixing cycle can be reduced suggest that for most large mixers no additional strength is developed after the charge has been held in the drum ¾ minute. If further tests confirm this, the mixer cycle could properly be reduced to about 60 seconds with the result that 60 batches an hour would represent full efficiency for a standard mixer. The studies which have so far been made suggest that it probably would be possible for the correlated equipment, except the crane, to meet this rate of production with almost no change in the amount of labor employed. Much better supervision, however, will be required if any real advantage is to be had from a mixer cycle as short as this, for feeding a mixer at a steady rate of one batch a minute will require an attention to the details of organization and the coordination of all parts of the work which have as yet but very rarely been attained in paving work.

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